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PHOENIX METROPOLITAN AREA EXTERNAL TRIP STUDY

Volume I
Final Report

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16. ABSTRACT

The Maricopa Association of Governments Transportation Planning Office is updating the computer models used to prepare forecasts of traffic volume in the Phoenix area. One element of the modeling effort involves external travel or trips having both origin and destination outside the area but passing through the area.

Roadside interviews were conducted togather data on such trips to aid in model calibration. Specifically, data was gathered on the following items:

1) Trip Origin
2) Trip Destination
3) Trip Purpose
4) Vehicle Garaging Location
5) Vehicle Occupancy
6) Vehicle Classification
7) Vehicle Registration

This document describes the procedures utilized in the gathering of the described data.

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EXTERNAL TRIP STUDY

Volume I
Statistical Procedures and Model Development

Prepared for

ARIZONA DEPARTMENT OF TRANSPORTATION
ARIZONA TRANSPORTATION RESEARCH CENTER

Prepared by

BARTON-ASCHMAN ASSOCIATES, INC.

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1. INTRODUCTION

All major metropolitan areas in the United States currently have ongoing transportation planning programs. In the Phoenix, Arizona metropolitan area, the Maricopa Association of Governments Transportation and Planning Office (MAGTPO) has the responsibility for this program. Information from this program is used to derive design year traffic forecasts which are the basis for all roadway improvement projects in the metropolitan area. Needless to say, it is essential to periodically update methods and procedures to produce reliable results.

STUDY PURPOSE

MAGTPO is currently involved in a major effort to update all aspects of the transportation model for the Phoenix metropolitan area. One component of this model estimates external travel, which is travel through the region and into the region. The purpose of the study described here was to update the external travel portion of this model to reflect current conditions and advancements in the state-of-the-art.

STUDY OBJECTIVES

This study had four broad objectives:

1. To collect, in a cost-effective way, current data on travel which passes through the Phoenix region, or which originates, or is destined to the Phoenix region and passes through the cordon line;

2. To organize these data into trip tables that can be used with the existing model and data to evaluate the impact of 1985 travel on purposes, policies, or transportation improvements;

3. To devise a method(s) of estimating external travel in the Phoenix region in the years 1990, 1995, 2000, and 2015; and

4. To determine the applicability of the methodology to Tucson and other metropolitan areas.

STUDY PROCEDURE

Roadside interview surveys were conducted at the seventeen external stations on the Phoenix highway network defined by MAGTPO. The survey obtained seven categories of information, as follows:

1. Trip origin;

2. Trip destination;

3. Trip purpose;

4. Vehicle garaging location;

5. Vehicle occupancy;

6. Vehicle classification; and

7. State of vehicle registration.

As part of this effort, a separate vehicle classification count was also performed. Specific details relating to the conduct of the survey are described in Volume II of this report, "Procedures Manual."

Volume I contains six chapters. Chapter 2 summarizes the results of a literature search performed to ascertain any recent research results concerning external trip studies. In Chapter 3, the sampling procedures used in the study are described. This is followed by a discussion in Chapter 4 of the coding and factoring of the survey results. Chapter 5 discusses the suggested modeling approach, as well as certain preliminary survey results. Finally, Chapter 6 describes development of the external trip model and the transferability of that model to other areas.

2.

LITERATURE SEARCH

This chapter will describe briefly the literature review undertaken in developing the methodology utilized for the External Trip Study for Phoenix. The major considerations in reviewing prior experience in conducting external surveys involve coming to grips with the following issues:

- How to contact travelers entering or exiting the study area,
- How to obtain data from these travelers,
- The role of sampling technique and sample size requirements for sampling travelers, and
- The hours of observation.

The publication Urban Origin-Destination Studies published by the United States Department of Transportation is a major source of information on the external survey. That document devotes an entire section, Chapter 6, "The External Survey," to the subject.

This reference lists three basic types of external survey techniques -- the roadside interview, the postcard survey, and the license plate (registration) survey. The following statements are reproduced from that report:

"The roadside interview -- In this technique, a sample of vehicles is stopped at each roadside interview station. An interviewer obtains the desired information by questioning the driver, and then the vehicle proceeds. A good interviewer should be able to complete an interview within one or two minutes. This is the technique that has been used in hundreds of studies over the past thirty years.

Advantages:

1. The most complete and accurate information is usually obtained when a personal contact is made between respondent and interviewer.

2. The response rate is greater (relative to the voluntary return technique), thereby minimizing the survey bias.

3. Samples can be chosen from a traffic stream to satisfy planned statistical standards.

Disadvantages:

1. This technique is more expensive than the other techniques described here, because a larger number of personnel are required.

2. On high volume facilities there may be some traffic delays during the survey, especially during peak travel periods.

3. This technique is often dangerous, especially on high volume facilities, because survey personnel must operate on the highway and interfere with the regular flow of traffic.

The voluntary return postcard -- In this type of external survey postcards are handed to the drivers of all or a sample of vehicles passing through roadside stations. The drivers are asked to read the instructions, complete the form, and return it by mail, postage free. This technique has been used many times at toll facilities and on high volume highways where travel data are needed.

Advantages:

1. It is less expensive than the traditional approach, because fewer people are needed in the field.

2. The field work can be accomplished faster than by the roadside interview approach, because postcards are handed to the driver with minimum delay.

3. It is much less likely to delay traffic.

Disadvantages:

1. Personal contact is not made with respondent.

2. Fewer questions can be included on the questionnaire.

3. The response rate is usually quite low, averaging about 25 to 35 percent in many cases. Therefore, a significant bias may be found in the data; this limits the amount of analysis that can be performed.

4. This technique still requires stopping traffic.

License plate technique -- Some research has been done which indicates travel data can be collected successfully by using the technique of recording license plate numbers. The technique requires that an observation and recording of the license plate be made for each vehicle crossing an interview station. A mail-back questionnaire is then sent to the owner of the vehicle who then voluntarily sends it back with the necessary information filled in.

This technique has been done manually, and some research has also been completed using cameras to record license plate numbers. The success of the survey depends upon quick access to registration records to match a license number to a vehicle owner so that questionnaires can be sent out quickly. It is desirable to have registration records on computer tape to make this procedure more efficient.

In a traffic study conducted in Boston, the owners of vehicles were located by using automated registration files and then contacted and asked to return a questionnaire. The following summarizes the major results:

Total questionnaires sent out	4805
Overall return rate:	
In-state respondents	64.8%
Out-of-state respondents	59.8%

Another study was undertaken to test a postal survey technique in Kansas using automated registration files. The following summarizes the major results:

Total vehicles sampled	17,300
Sample rate	25%
Overall return rate	52.8%

Advantages:

1. This has the same advantages as the voluntary return postcard technique; it is in effect, a variation of that technique.

2. In addition, this technique is safer, because traffic is not stopped.

3. If a camera is used to record license plate numbers there will be a smaller number of field personnel needed.

4. The research cited above indicates the response rate may be higher, as compared to the voluntary return postcard technique.

Disadvantages:

1. Personal contact is not made with respondents.

2. Fewer questions can be asked, because of the voluntary response.

3. Night operation is difficult.

4. There is still a response bias that must be carefully controlled.

5. It is difficult to use economically and efficiently unless all motor vehicle registrations are on computer tape, because quick access is needed to obtain vehicle addresses and send out the questionnaires. (The questionnaire should be mailed out within 24 hours to be most effective.)

   This requirement is further complicated by out-of-state vehicles. If there is a substantial volume of such vehicles registered in states that do not have computerized registration records, it will be extremely difficult to mail out the questionnaires."

Barton-Aschman Associates, Inc. recommends the roadside interview for the Phoenix area over the postcard survey because it is believed that the sampling technique recommended reduces significantly the crew size. No more than three roadside interviewers are needed at any time and when a fewer number are needed, the other interviewer(s) and relief person can edit and code. The other personnel, police, manual classifiers, crew chief, and flagmen are common to both techniques. The safety factor can be maximized by hiring police protection and being certain that a police car with flashing lights is conspicuous at the station during all hours of operation.

Finally, the use of sampling combined with a station set up to bypass non-sampled vehicles avoids any delay except to sampled vehicles, which is held to a maximum of two minutes. The disadvantages of the postcard technique, on the other hand, seem to be fatal flaws in the opinion of the consultant. This is especially true of the lack of personal contact and the low response rate, which requires a higher initial sample. These comments apply to the license plate technique, as well.

A major reason the roadside interview approach was selected was that a sample technique can be used to overcome the disadvantages as discussed in the U.S. DOT report. The sample technique was reported on in the <u>Final Report of the Chicago Area Transportation Study</u>, (July 1971, page III-45).

This formula draws on sampling theory which states that the precision of a sample estimate basically is inversely proportional to the square root of the sample size:

$$\sigma_p = \sqrt{\frac{pq}{n} \times \frac{m-n}{m-1}}$$

where: σ_p = standard error of proportion p

p = proportion of sample possessing a given attribute such as trip purpose to work

q = 1-p

n = number in sample

m = universe size

This formula can be solved for different precision levels and values of p. If we assume p=q=0.5 and if we set p to be equal to plus or minus 0.05, we can solve for a sample rate guaranteed to give a standard error ± 0.05, which is ± 10% at the 68% confidence level for values of p approaching 0.5. If one accepts this precision for a single hour, one can solve to find the sample size as follows:

$$0.05 = \sqrt{\frac{0.25}{n} \times \frac{(m-n)}{(m-1)}}$$

and

$$n = \frac{100\ m}{m+99}$$

This means that the largest absolute sample size for a given time period (one hour) is 100 for this level of precision. Of course, for the combined two-hour peak-period, the precision would be much greater (±0.07%) and for the entire period of interviewing the precision of estimates based on the sample would be very high (assuming 12 hours @100, ±2.8%). However, if 100 is the maximum sample size for any hour, it suggests that an interview crew of three would be adequate. For low volumes such as 25 vehicles per hour, 20 samples would be taken.

The last major concern was with the hours of operation. Twenty-four hour operation means expensive operation because of the costs of lighting the station and providing three shifts of police protection. In addition, the risk of an accident at a station is greatly increased by nighttime operations. Lastly, the volume of traffic during the hours of darkness is a small proportion of the twenty-four hour total.

According to the U.S. DOT report on the external survey, ". . . the experience of several States has indicated that a station operated during daylight hours only provides data that adequately represents travel."

The Highway Research Information Service (HRIS) was contacted and a computer search located a variety of publications that relate to the external roadside interview. The abstracts of these reports are listed in Appendix A.

3.

SAMPLING PROCEDURES

This section discusses the sample size requirements for the External Trip Study.

PRECISION REQUIREMENTS

Sampling permits the estimation of the value of attributes of a population at a specified level of accuracy. For example, if one wished to know the proportion of compact cars in the traffic stream on a given day, one could count the total vehicles passing and also the number of compacts. The ratio of the latter to the former is the desired statistic. However, one would not have to count all of the vehicles and all of the compacts. One could count a sample of the vehicles, and classify them according to whether or not they were compact. Because all of the vehicles were not counted and classified, the estimated proportion of vehicles that are compacts is subject to sampling error.

What this means is that if one were to estimate the proportion of compact cars based on a sample count of 100 and found the proportion to be 0.4 or 40 percent, the estimate of 40 percent could be high or low in comparison to the proportion that might be obtained if 100 percent of the vehicles were classified. This accuracy is usually expressed as the standard error of the proportion and the formula for the standard error is:

$$\sigma_p = \sqrt{\frac{pq}{n}}$$

where: σ_p = standard error of the proportion p

a = number in sample with attribute a (e.g., compact cars)

n = number of samples

p = the proportion of the sample possessing attribute a

$$p = \frac{a}{n}$$

q = the proportion of sample elements not possessing attribute a = 1-p.

In the case of our hypothetical example:

$$p = \sqrt{\frac{(0.4)(0.6)}{100}} = 0.04899$$

Since the proportion of compacts in the sample comes to 0.4, the standard error of the proportion is 12.25 percent of the proportion [(100)(0.04899)/0.04].

One standard error represents the 68 percent confidence level. This means that if the experiment were repeated 100 times, 68 times the estimate of the proportion of compacts would fall within a range defined as the sample proportion plus or minus one standard error or 0.4 $\pm$ 0.04899 or between 0.35101 and 0.44899. If greater accuracy is desired, the sample size must be increased. For example, if an accuracy level of $\pm$ 5 percent of the expected 0.4 proportion is desired, the standard error would be 0.02. The sample size required would be

$$0.02 = \sqrt{\frac{(0.4)(0.6)}{n}} \qquad n = 600$$

Also, if greater confidence in a specified level of accuracy is desired, the sample size must be increased. The confidence level of one standard error is 68 percent. If 90 percent confidence is desired, 1.645 standard errors are required and, for the 95 percent confidence level, 1.96 standard errors are needed. For example, if we desired $\pm$ 10 percent at the 95 percent confidence level, we need a standard error of 0.0204082 (0.04/1.96). The sample size needed would be

$$0.0204082 = \sqrt{\frac{0.24}{n}} \qquad n = 576$$

Sample size requirements are thus a function of confidence level and precision desired. There is one additional factor to consider and that is adjusting for finite populations. If the precision requirements call for a sample of 576 samples, and there are only 200 elements in the population, the sample size cannot be 576. This adjustment is given in the following equation, where m is the population size.

$$\sigma_p = \sqrt{\frac{pq\ (m-n)}{nm}}$$

If we assume $p = 0.5 = q$,

and an accuracy of $\pm$ 0.05 (10 percent), the equation reduces to

$$0.05 = \sqrt{\frac{0.25\ (m-n)}{nm}}$$

$$0.0025 = \frac{0.25\ (m-n)}{nm}$$

$$nm = 100\ (m-n)$$

$$nm + 100n = 100m$$

$$n = \frac{100\ m}{m+100}$$

This equation gives the samples required for relative error at the 68 percent confidence level of plus or minus ten percent (0.05/0.5=0.1).

For our case of a population of 200, the sample size would be 67. If the population total were 2,000, the sample size would be 95. For a population total of 20,000, the sample size would be 100. For a population of 2,000,000, the sample size would also be 100.

This sample size approach is the one that was recommended for use in the external study. It gives a number of samples that is fixed at 100 or less for any approach volume per hour. The major survey stations operated approximately 14 hours a day, with no hour requiring more than 100 vehicles to be stopped. Were we to operate at 100 per hour for 14 hours, we would obtain 1,400 samples in one direction. The accuracy of such a sample for the entire day would be 0.01336 which, assuming a p of 0.5, gives a relative error of 2.67 percent at the 68 percent confidence level and an error of 4.40 percent at the 90 percent confidence level.

ILLUSTRATION OF THE SAMPLING APPROACH

This approach is illustrated in Exhibit 1 for Buckeye Road, westbound between El Mirage and 115th Avenue, using count data for Thursday, December 6, 1984.

This procedure would yield 1,049 samples and an accuracy of $\pm$ 0.015 or $\pm$ 3 percent at the 68 percent confidence level and $\pm$ 5 percent at the 90 percent confidence level. Yet for each of the daylight hours, the hourly accuracy would be $\pm$ 10 percent at the 68 percent confidence level. For a two-hour peak period, the accuracy would be $\pm$ 4 percent at the 68 percent confidence and $\pm$ 6.7 percent at the 90 percent confidence level. Operating during daylight hours only, we would be sampling some 83 percent of the 24-hour volume and our sample total of 1,049 would represent a 20 percent sample of that total volume.

EXHIBIT 1

EXAMPLE OF RECOMMENDED SAMPLING APPROACH

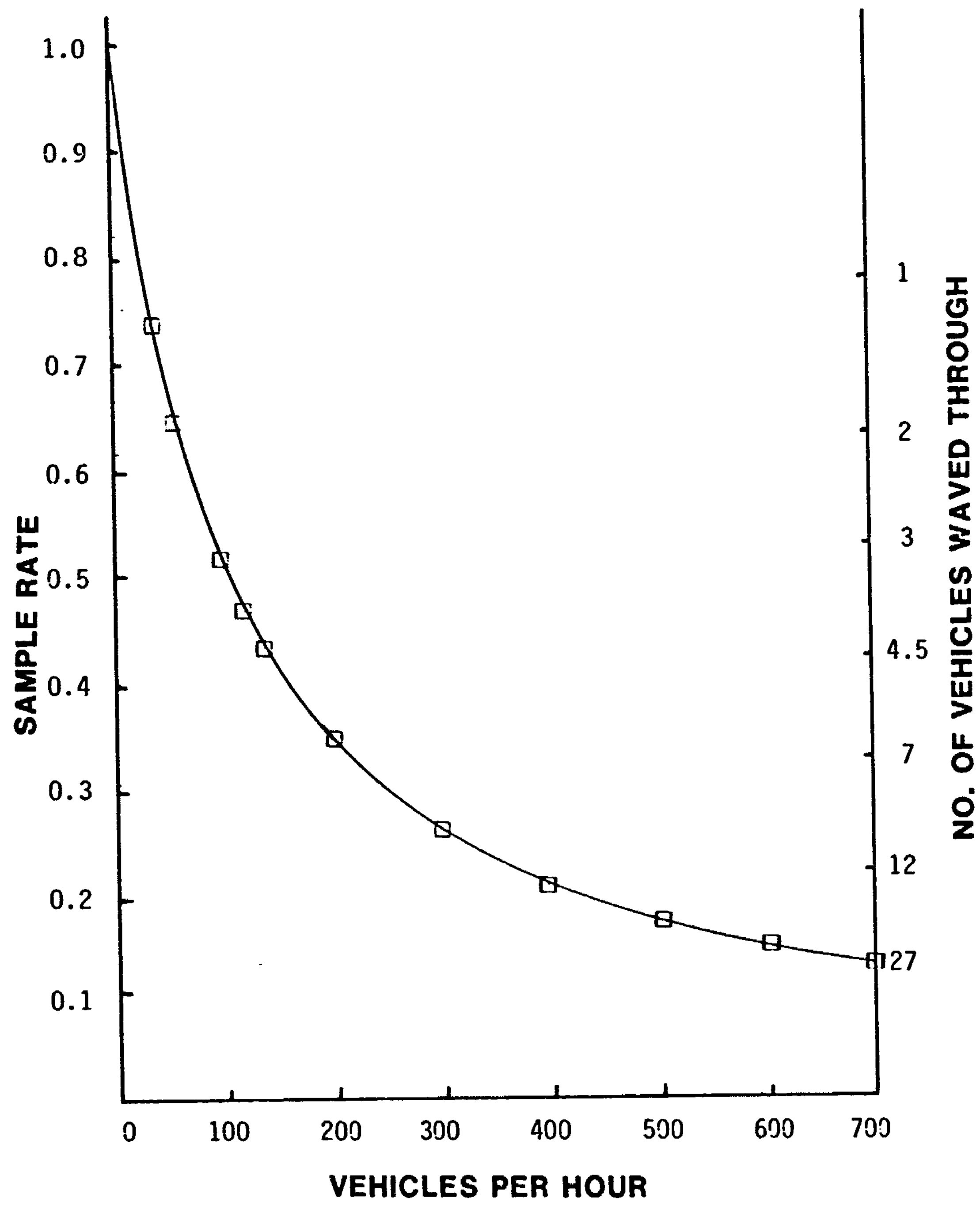
BUCKEYE ROAD

Start Hour	Volume	Number of Samples
0	58	Not Operated
1	44	" "
2	43	" "
3	30	" "
4	41	" "
5	153	" "
6	240	71
7	388	80
8	270	73
9	303	75
10	295	75
11	304	75
12	271	73
13	289	74
14	331	77
15	385	79
16	452	82
17	419	81
18	306	75
19	142	59
20	155	Not Operated
21	130	" "
22	127	" "
23	101	" "
Total	5,277	1,049

GRAPHIC ILLUSTRATIONS

Exhibit 2 illustrates the sample size as a percent of the approaching vehicles and also the cars that must be waved through assuming a three-person interviewing team.

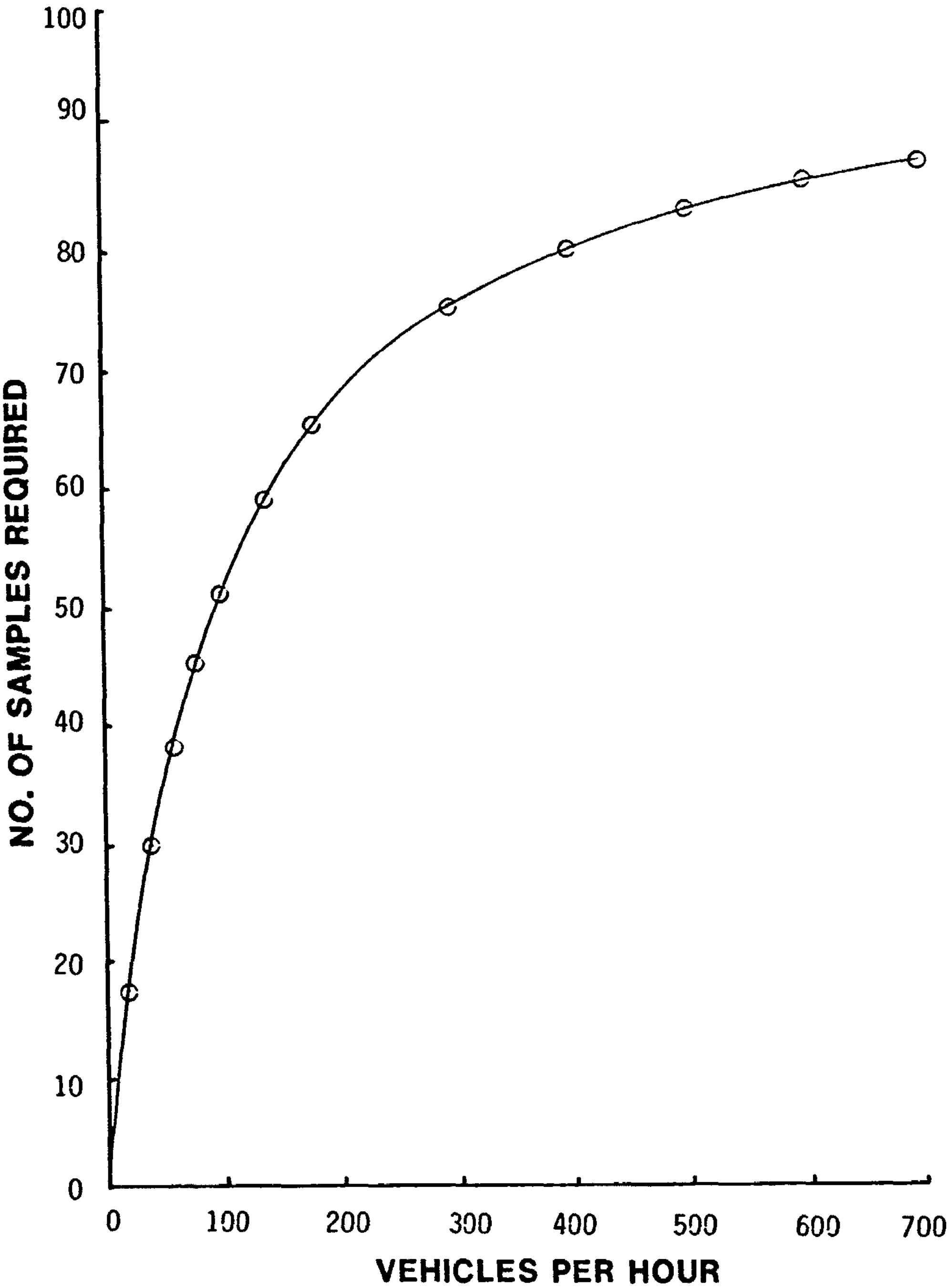
Exhibit 3 illustrates the number of samples required per hour given a specified approach volume.



SAMPLE RATE AS A FUNCTION OF
APPROACH VOLUME (ASSUMING 3 INTERVIEWERS)

BARTON ASCHMAN ASSOCIATES, INC.

EXHIBIT 2



REQUIRED SAMPLE
AS A FUNCTION OF HOURLY APPROACH VOLUME*

BARTON-ASCHMAN ASSOCIATES, INC.

EXHIBIT 3

* ±10 Percent Error at 68 Percent Confidence

4.

GEOCODING AND TRIP FACTORING

This section describes the conventions employed in coding origin/destination responses on the External Trip Survey.

Internal Zones

Internal zones were coded with their four-digit traffic analysis zone (TAZ) number, based on the MAG 1,193 zone system. Thus, the codes range from 0001 to 1193.

External Zones

Several versions of external zones were coded. Again, the codes were four-digit numbers, but the first digit in the sequence was a number other than 0 or 1. In this way the external zones (which begin with 2 - 9) can be readily differentiated from the internal zones (which begin with 0 or 1).

The external trips from unincorporated parts of Maricopa County were given external codes to represent the directional octant from which they came:

Directional Octant	External Station	Code
W	1194, 1195, 1196	2930
NW	1197	2931
N	1198, 1199	2932
NE	1200	2933
E	1201, 1202	2934
SE	1203 - 1207	2935
S	1208 - 1210	2936

Locations within Arizona, but outside the MAG study area, were assigned four-digit codes beginning with a 2 and followed by a place code previously adopted for use by MAG. Exhibit 4 contains a listing of these locations, including the code used here as well as the TAZ number.

Finally, codes were devised for trips beginning or ending outside Arizona. These codes begin with 3 - 9, as follows:

Origin/Destination	Code
Northern California	3100
Southern California (Los Angeles Area)	3200
Southern California (San Diego Area)	3300
Nevada	4000
Utah	5000
New Mexico	6000
Texas	7000
Colorado	8000
Other	9000

EXHIBIT 4

EXTERNAL CODES

Place Code	TAZ	Name	Place Code	TAZ	Name
2005	1268	Ajo (U)	2295	1219	St. Johns
2015	1213	Bagdad (U)	2297	1238	San Carlos (U)
2020	1275	Benson	2299	1267	San Luis
2025	1285	Bisbee	2300	1266	San Manuel (U)
2030	1234	Buckeye	2307	1205	Sedona (U) (Part)
2032	1241	Bylas (U)	2307	1205	Sedona (U) (Part)
2035	1254	Casa Grande	2310	1221	Show Low
2053	1207	Chino Valley	2315	1283	Sierra Vista
2055	1209	Clarkdale	2320	1217	Snowflake
2060	1235	Claypool (U)	2325	1265	Somerton
2065	1243	Clifton	2340	1273	South Tucson
2070	1248	Coolidge	2345	1223	Springerville
2073	1210	Cottonwood	2350	1242	Stargo (U)
2080	1286	Douglas	2355	1240	Superior
2085	1259	Duncan	2357	--	Surprise
2090	1224	Eagar	2358	1218	Taylor
2105	1255	Eloy	2365	1256	Thatcher
2115	1201	Flagstaff	2370	--	Tolleson
2120	1247	Florence	2375	1277	Tombstone
2123	1282	Fort Huachuca (U)	2380	1271	Tucson
2125	1194	Fredonia	2283	1263	Wellton
2129	1251	Gila Bend	2385	1260	West Yuma (U)
2145	1237	Globe	2390	1225	Wickenburg
2155	1196	Grand Canyon (U)	2395	1272	Willcox
2160	1246	Hayden	2400	1200	Williams
2165	1203	Holbrook	2401	1200	Williams (U)
2170	1280	Huachuca	2405	1249	Winkelman
2175	1208	Jerome	2410	1202	Winslow
2180	1245	Kearny	2415	1261	Yuma
2185	1199	Kingman	2425	1252	Yuma Proving Ground (U)
2187	1214	Lake Havasu City	2430	1252	Yuma Station (U)
2205	1264	Mammoth	2901	1206	Apache County (Unincorp. part)
2210	1269	Marana	2903	1276	Cochise County (Unincorp. part)
2220	1236	Miami	2905	1197	Coconino County (Unincorp. part)
2235	1284	Nogales	2907	1227	Gila County (Unincorp. part)
2238	1270	Oro Valley	2909	1258	Graham County (Unincorp. part)
2240	1195	Page (U)	2911	1239	Greenlee County (Unincorp. part)
2245	1222	Parker	2913	1229	Maricopa County (Unincorp. part)
2250	1281	Patagonia	2915	1198	Mohave County (Unincorp. part)
2252	1220	Payson (U)	2917	1211	Navajo County (Unincorp. part)
2265	1250	Pima	2919	1274	Pima County (Unincorp. part)
2275	1244	Plantside (U)	2921	1253	Pinal County (Unincorp. part)
2280	1215	Prescott	2923	1279	Santa Cruz County (Unincorp. part)
2282	1216	Prescott Valley	2925	1204	Yavapai County (Unincorp. part)
2290	1257	Safford	2927	1262	Yuma County (Unincorp. part)

EXTERNAL SURVEY TRIP FACTORS

This section addresses the problem of inserting factors into the External Survey records so that the sum of these factors across all records in one direction at one external station matches the total number of vehicles passing through that station in the same direction.

A. <u>There are basically two factors</u> to be calculated:

1. A factor to account for the fact that vehicles were sampled out of the traffic stream during the period of time for which the station was operated. Basically 6:00 a.m. to 7:00 p.m. for the high-volume stations and 10:00 a.m. to 7:00 p.m. for the low-volume stations. The sum of the factors for all sample records from a station operated in one direction should equal the manual count of vehicles passing through the station during its hours of operation. We will call this factor F_{13} or F_9 or F_n where n equals the hours of interviewing.

2. A factor to account for the fact that the station was operated for less than 24 hours -- designate this factor as F_{24}.

B. <u>The 24-hour factor F_{24}</u>. This factor is the product of the F_9 or F_{13} and an adjustment factor obtained from the 24-hour automatic counters. This adjustment is obtained for each station direction (inbound/outbound). In other words, we assume that the ratio of the vehicles manually counted during the station hours of operation to the 24-hour total vehicles is the same as the ratio of the machine count for the same time period to the 24-hour machine count period. For example, suppose we have the following:

	Manual Count		Automatic Machine Counter	
	13 Hour	24 Hour	13 Hour	24 Hour
Station X	7,534	?	7,315	8,200

The adjustment factor from the machine count is 8,200/7,315 = 1.121. The estimate of the 24-hour count which would have been achieved if the manual count had continued for all 24 hours is equal to 1.121 x 7, 534 = 8,446. The adjustment factor F_A is 1.121. This factor will be calculated for all stations in each direction.

C. The Stratum Factor F_k. This factor raises the sample vehicles to the manual count of those vehicles. This factor is the ratio of the actual count of vehicles in a stratum to the number of completed interviews in that stratum.

A stratum is defined by vehicle type and time of day. The vehicles types are:

- Auto
- Van/Pickup
- Trucks = 6 tires
- Trucks > 6 tires
- Recreation Vehicles
- Motorcycles
- Buses

The driver of all vehicle types except buses was interviewed. The time periods are hourly during the period of station operations. However, at first thought, the hours should be combined to form a peak period and a midday period. The table of factors for a station in one direction would look as shown on Exhibit 5.

One of the potential dangers in the factoring process is the potential of finding a stratum with no samples in it. The solution to this is aggregation, either across time and/or across vehicle type. Candidates for vehicle aggregation classes are:

- Autos, Vans, and Pickups
- Trucks
- Recreation vehicles and motorcycles

The third category could, if necessary, be combined with autos, vans, and pickups.

The best way to review the need for aggregation is to prepare a table of completed interviews for each station for each direction by hour of day by vehicle type.

EXHIBIT 5

HYPOTHETICAL FACTORS FOR STATION X

Vehicle Type	Peak Period			Midday Period		
	Sample	Count	Factor	Sample	Count	Factor
Auto	75	300	4.0	200	1000	5.0
Van/Pickup	10	50	5.0	25	100	4.0
Truck = 6 Tires	5	20	4.0	8	50	6.25
Truck > 6 Tires	2	15	7.5	5	25	5.0
Recreation Veh.	4	10	2.5	2	15	7.5
Motorcycle	2	5	2.5	2	10	5.0
Bus	-	7	-	-	15	-

These factors are stratum factors, and are specified as:

$$F_S = \frac{M_S}{N_S}$$

where:

F_S = Factor for stratum S.
M_S = Number of vehicles counted in stratum S.
N_S = Completed questionnaires in stratum S.

Stratum factors will be calculated for each station by direction.

5.

SUGGESTED MODELING APPROACH

This chapter reviews the results of the external survey and outlines the approach for modeling external trips as part of the regional travel forecasting process. Objectives appropriate to the external model and major decisions from a modeling standpoint are also outlined.

OBJECTIVES

The following objectives are suggested in relation to the external model:

- o First, the model should make sensible use of the survey results and adequately reproduce observed external travel patterns;
- o The model should form a logical and consistent element of the overall model set;

- The model should be capable of reflecting major changes in future external travel;

- The model must be realistic in its requirement for exogenous data;

- The model should be efficient and reasonable from an application standpoint.

Specification and development of the model should reflect its relative importance as part of the overall travel forecasting process. Since external travel forms a small part of total travel on the region's facilities, a relatively simple approach is suggested.

KEY DIMENSIONS

Decisions must be made with respect to three key dimensions of the model structure:

- What form of model should be employed -- a synthetic model such as the gravity model or a growth-factoring procedure, for example?

- What geographic basis should be used -- zones versus districts, external zones versus cordon stations?

- To what extent should external travel be disaggregated for modeling purposes by trip purpose, vehicle type, time of day, etc.?

A growth-factoring approach is simple yet retains the observed travel patterns to a greater extent than a synthetic model. A synthetic model, on the other hand, can *potentially* reflect the impact of major new facilities and major redistributions of travel, but only if properly structured and calibrated to do so.

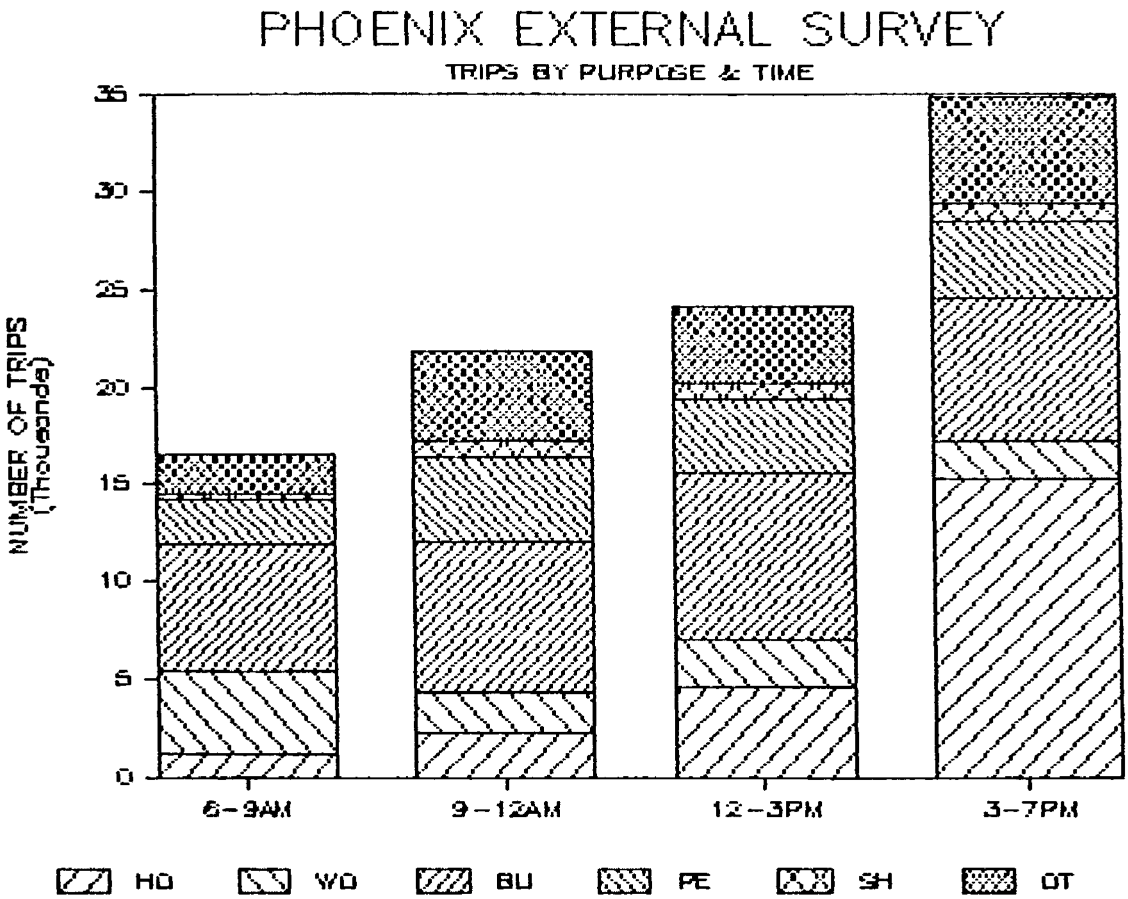
Ultimately, external travel must be combined with other regional trips to form total assignment matrices based on a geographic system of internal area traffic zones combined with external cordon station zones -- i.e., the external area is represented only by the external cordon stations, not by the system of external zones defined for the purposes of the survey. It is suggested that the external model be based on cordon stations rather than the external survey zones. This approach will be more efficient and will avoid the need to scale distances as in the special network developed for survey analysis.

Ideally, the model should reflect important variations in the survey data; however, the model can become unwieldy if an overly disaggregated approach is adopted. The extent of disaggregation should be stringently curtailed to avoid this situation.

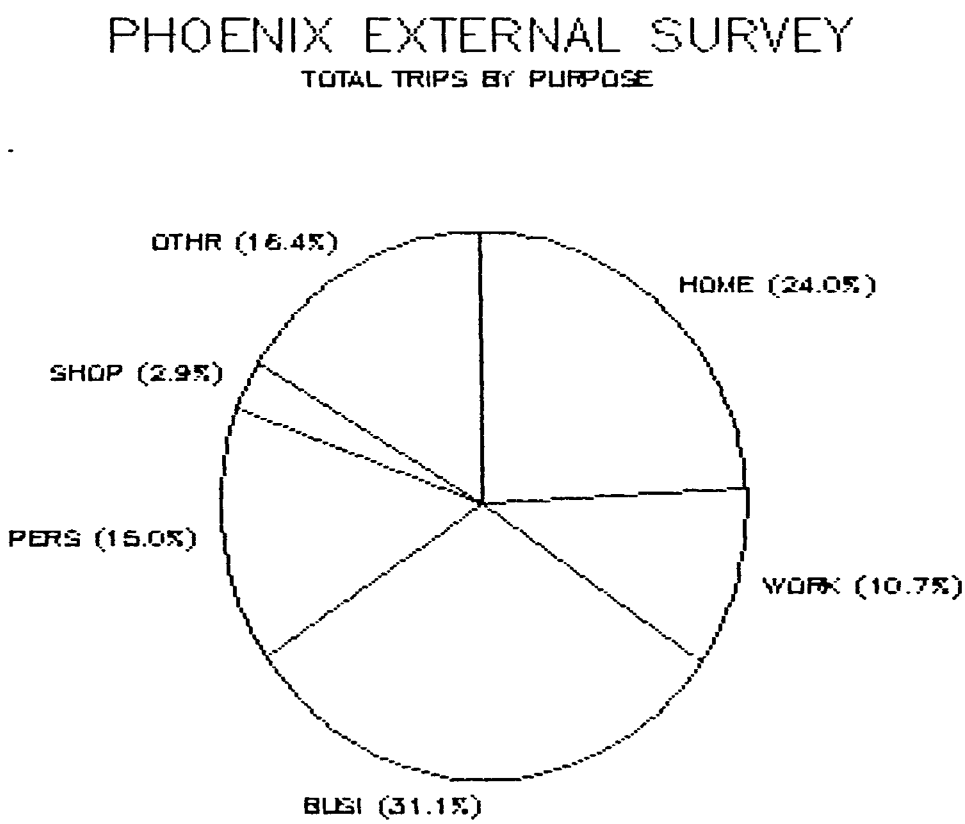
SURVEY RESULTS

The following exhibits illustrate external survey results. A tabulation of external survey data upon which the illustrations are based is also appended (See Appendices B and C). Exhibit 6 presents total expanded trips -- all stations combined -- by trip purpose and time of day. Total trips by period increase as the day progresses with the highest period being 3 - 7 PM (this is exaggerated by this being a four-hour period). The major cause for this temporal unevenness is trips for the purpose "HOME." Travel for the other purposes is much more nearly uniform over the day. The most common trip purpose is "BUSINESS." By contrast, WORK and SHOP are minor categories. In

EXHIBIT 6



PHOENIX EXTERNAL SURVEY
TRIPS BY PURPOSE & TIME
NUMBER OF TRIPS (Thousands)
35
30
25
20
15
10
5
0
6-9AM
9-12AM
12-3PM
3-7PM
HO
WO
BU
PE
SH
OT



PHOENIX EXTERNAL SURVEY
TOTAL TRIPS BY PURPOSE
OTHR (16.4%)
HOME (24.0%)
SHOP (2.9%)
PERS (15.0%)
WORK (10.7%)
BUSI (31.1%)

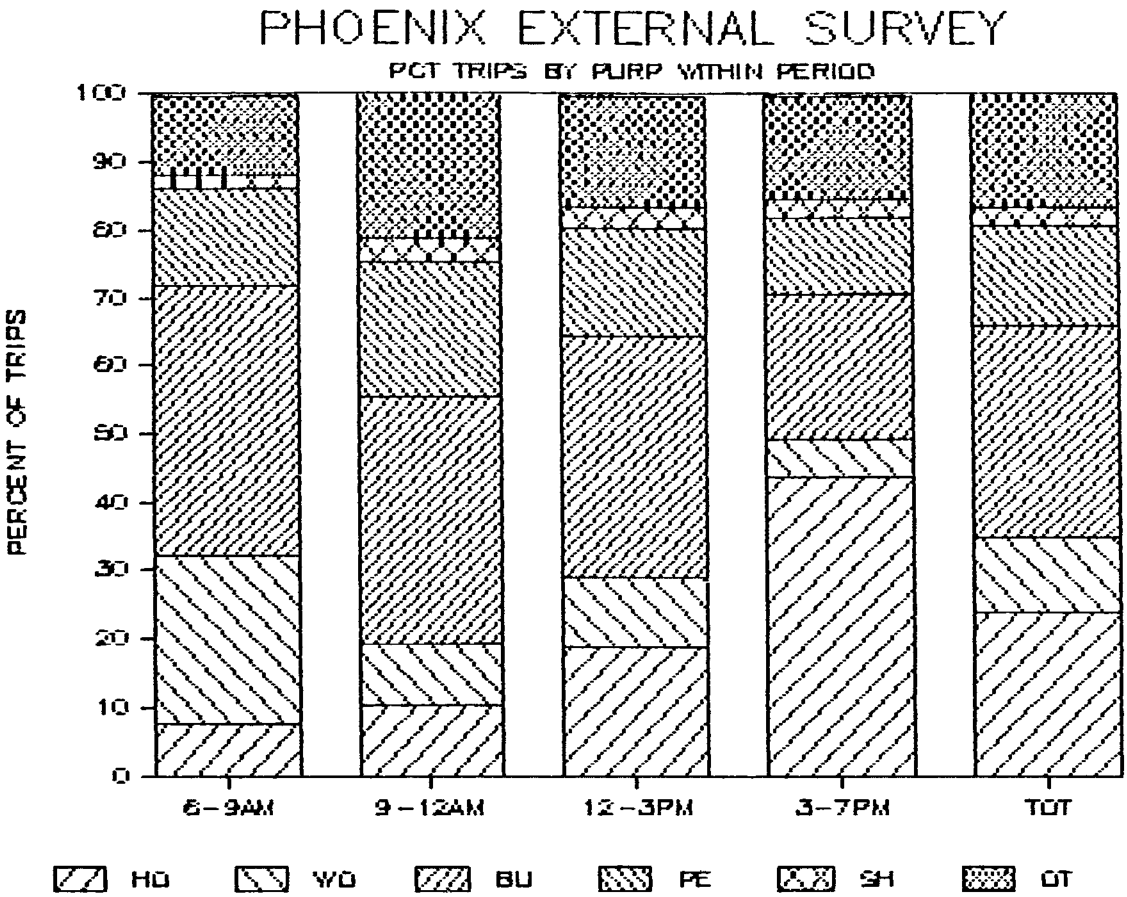
some of these exhibits, SOCIAL-RECREATION and OTHER trips have been combined since OTHER was a small category and only six subdivisions could be shown. The purpose breakdown is clearly very different than for internal trips, with a much smaller proportion related to HOME. The breakdown of external trips by purpose is further illustrated in Exhibit 7.

The breakdown of trips by vehicle type is shown in Exhibit 8. Trips by AUTO dominate, but there are a considerable number of trips by PICKUP/VAN (PUPV). Trucks account for a substantial portion of the WORK and BUSINESS trips, but not for other purposes, as would be expected. Very few trips were recorded by RECREATIONAL VEHICLES (RECV) or by MOTORCYCLE (MCYC).

Trip-length characteristics are illustrated in Exhibit 9. WORK and SHOP trips have relatively short average trip lengths, indicating they are more local in nature than other external trips. SOCIAL-RECREATION and OTHER trips have the longest trip length, as might be expected. Average trip length by vehicle type exhibits less deviation from the average but shows expected patterns in that RECV and 6+AXLE TRUCKS (6+TRK) have longer-than-average trip lengths and MCYC's have the shortest trip length. A detailed tabulation of trips and average trip distance for each station, cross classified by trip purpose and vehicle type, is presented in Appendix B.

Average trip length and total number of trips for each station are presented in Exhibit 10. As indicated, there is considerable variation in traffic volume and trip length among the stations. There is some tendency for average trip length to vary directly with the station volume, but this tendency is far from complete. The distribution of opportunities for each station also is a likely influence on trip length, but it is unlikely to fully explain the variation among stations — indeed, no single factor or variable is likely to do so. The distribution of external trips is

EXHIBIT 7


PHOENIX EXTERNAL SURVEY
PCT TRIPS BY PURP WITHIN PERIOD
PERCENT OF TRIPS
0
10
20
30
40
50
60
70
80
90
100
6-9AM
9-12AM
12-3PM
3-7PM
TOT
HO
WO
BU
PE
SH
OT

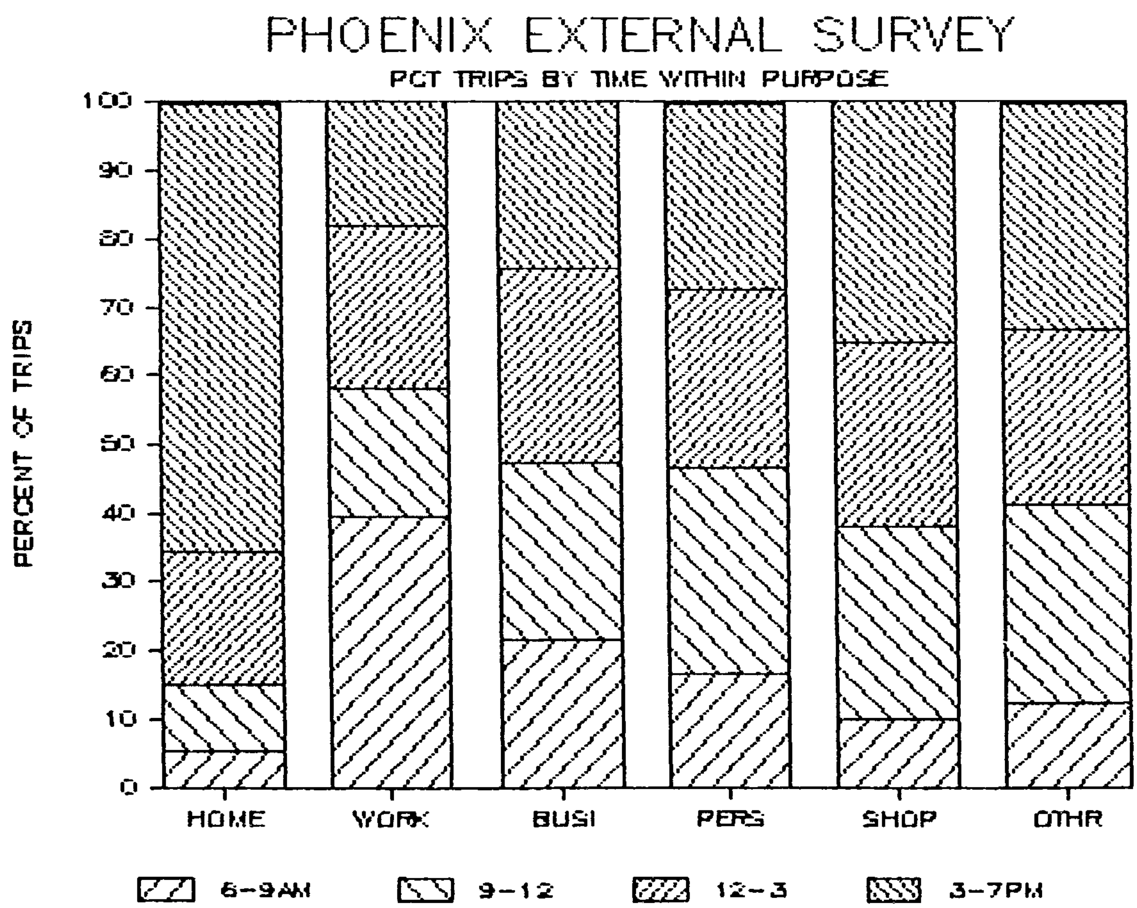
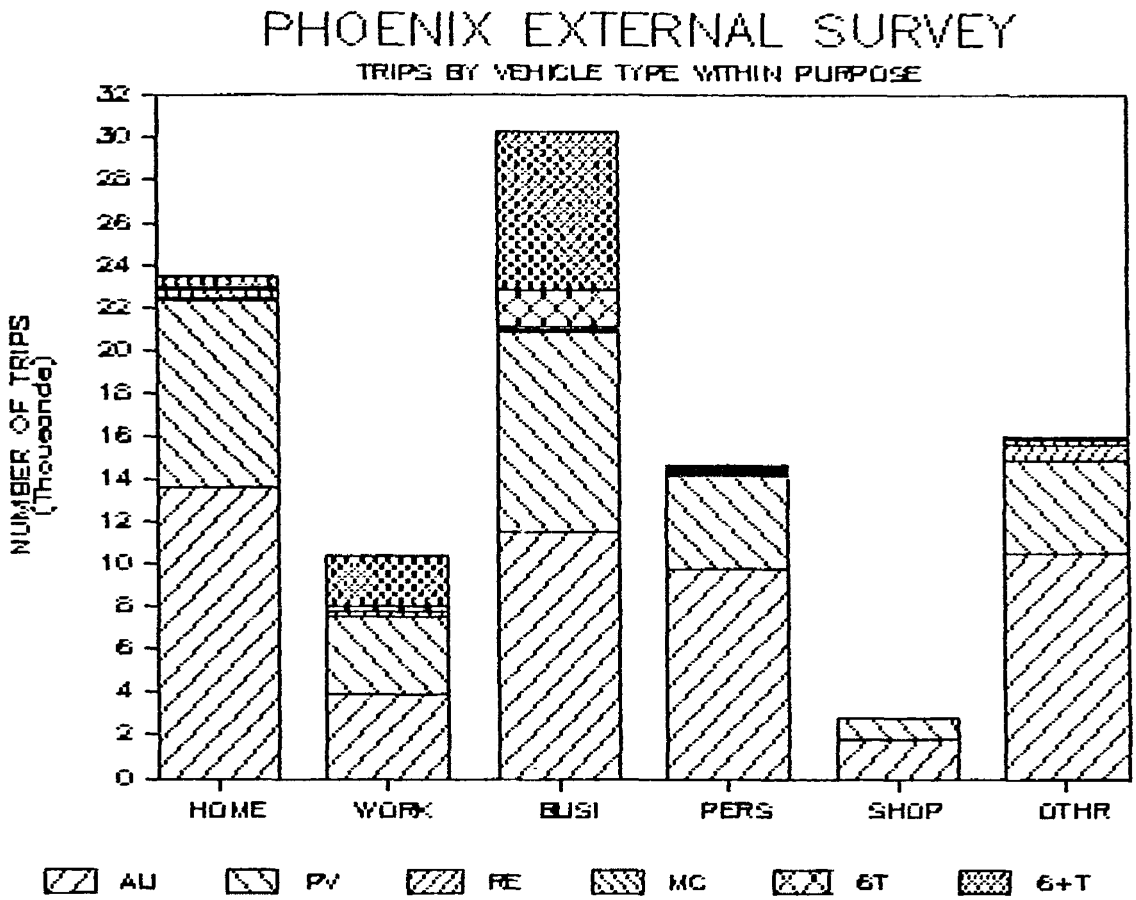
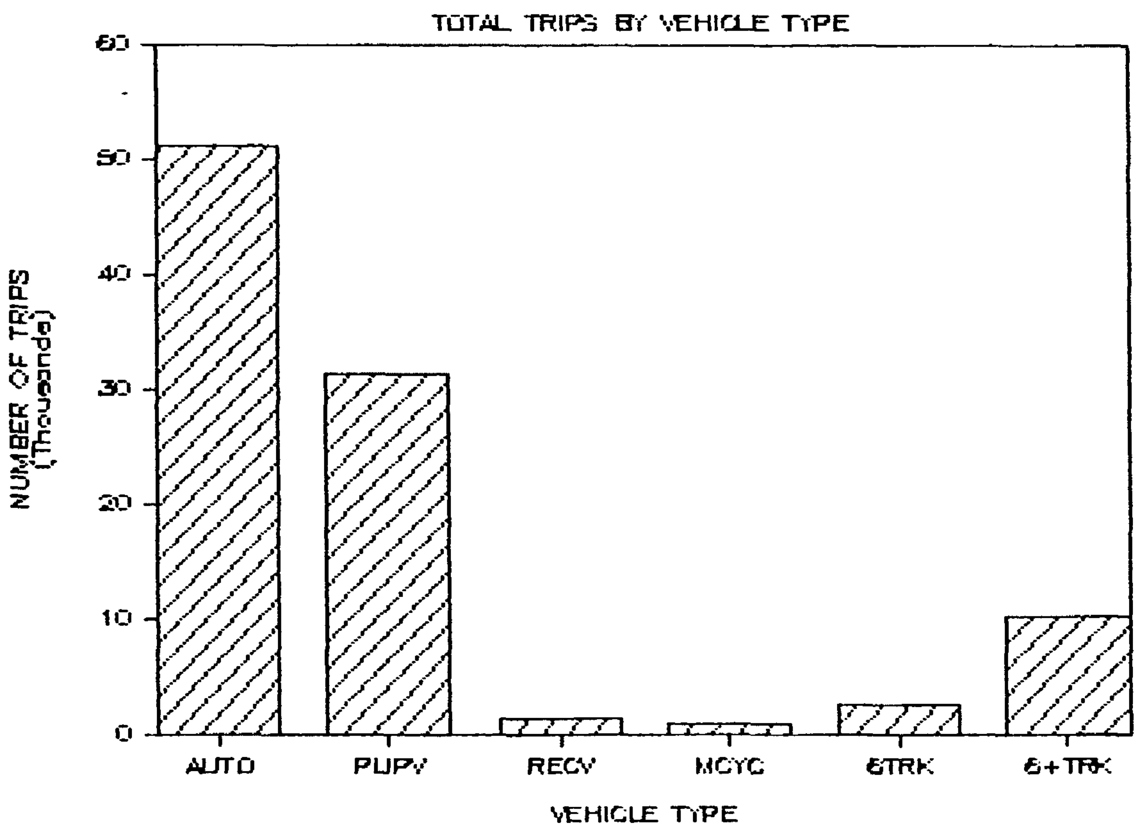

PHOENIX EXTERNAL SURVEY
PCT TRIPS BY TIME WITHIN PURPOSE
PERCENT OF TRIPS
0
10
20
30
40
50
60
70
80
90
100
HOME
WORK
BUSI
PERS
SHOP
OTHR
6-9AM
9-12
12-3
3-7PM

EXHIBIT 8

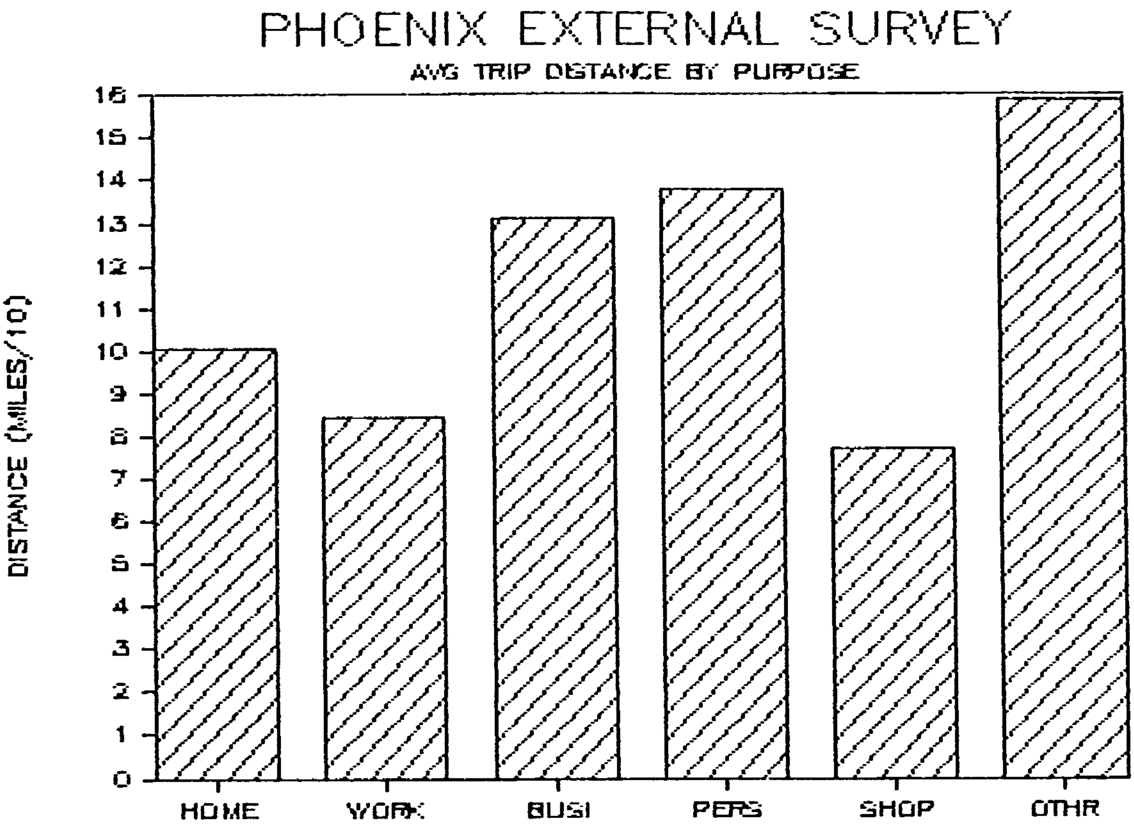


PHOENIX EXTERNAL SURVEY
TRIPS BY VEHICLE TYPE WITHIN PURPOSE
NUMBER OF TRIPS (Thousands)
HOME
WORK
BUSI
PERS
SHOP
OTHR
AU
PV
RE
MC
6T
6+T



TOTAL TRIPS BY VEHICLE TYPE
NUMBER OF TRIPS (Thousands)
AUTO
PUPV
RECV
MCYC
6TRK
6+TRK
VEHICLE TYPE

EXHIBIT 9


PHOENIX EXTERNAL SURVEY
AVG TRIP DISTANCE BY PURPOSE
DISTANCE (MILES/10)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
HOME
WORK
BUSI
PERS
SHOP
OTHR

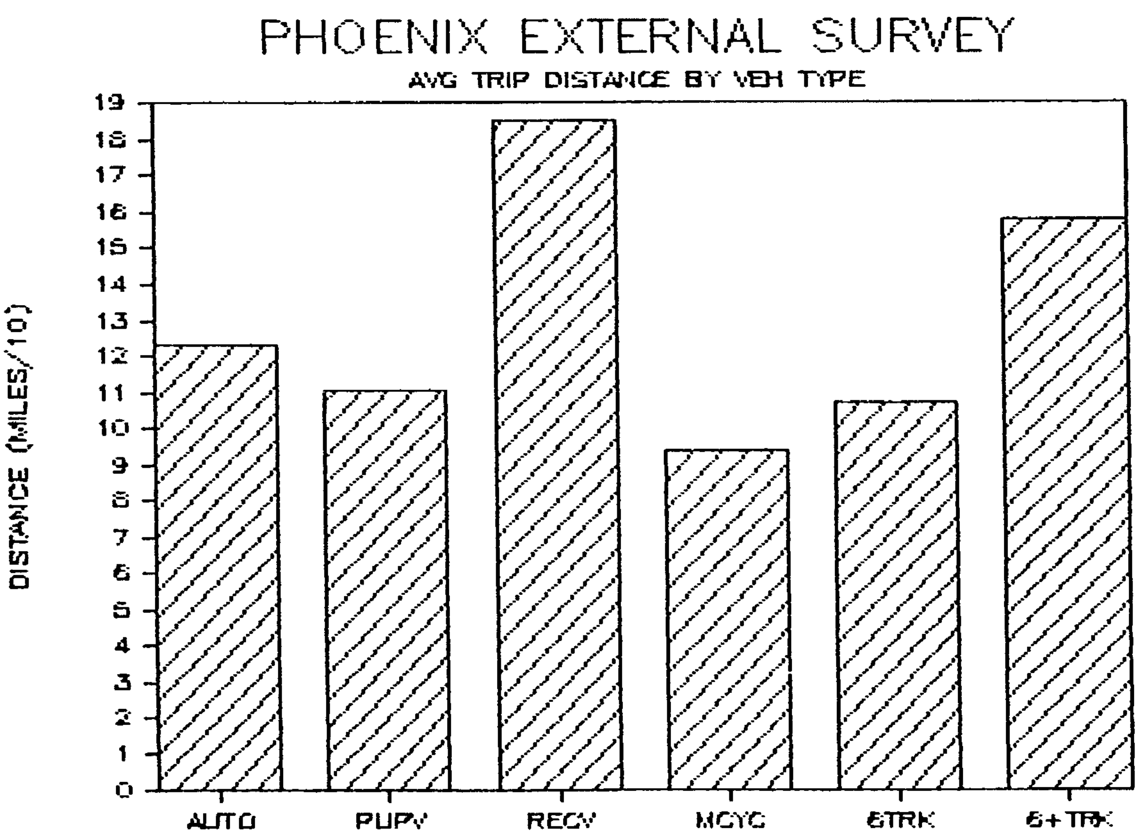
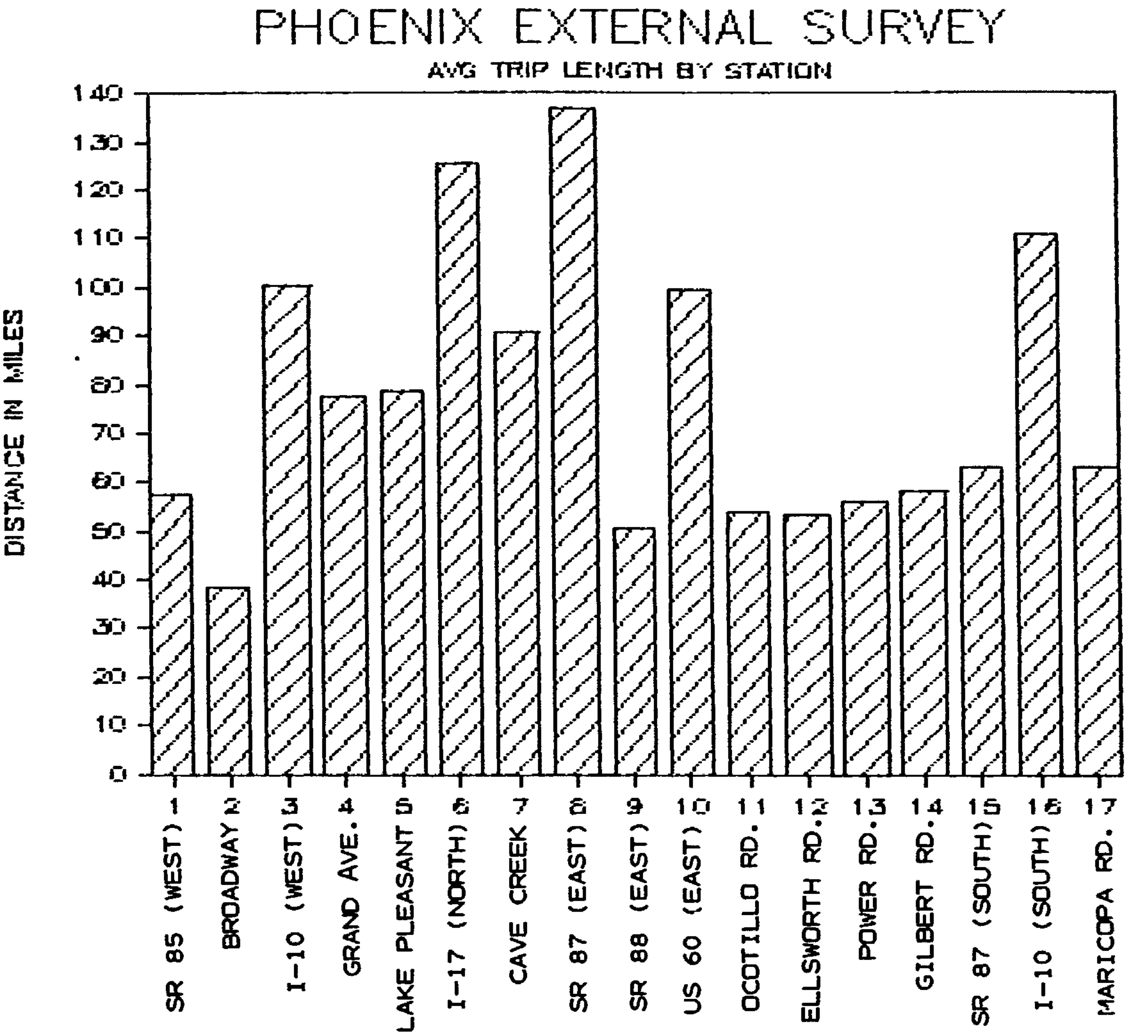
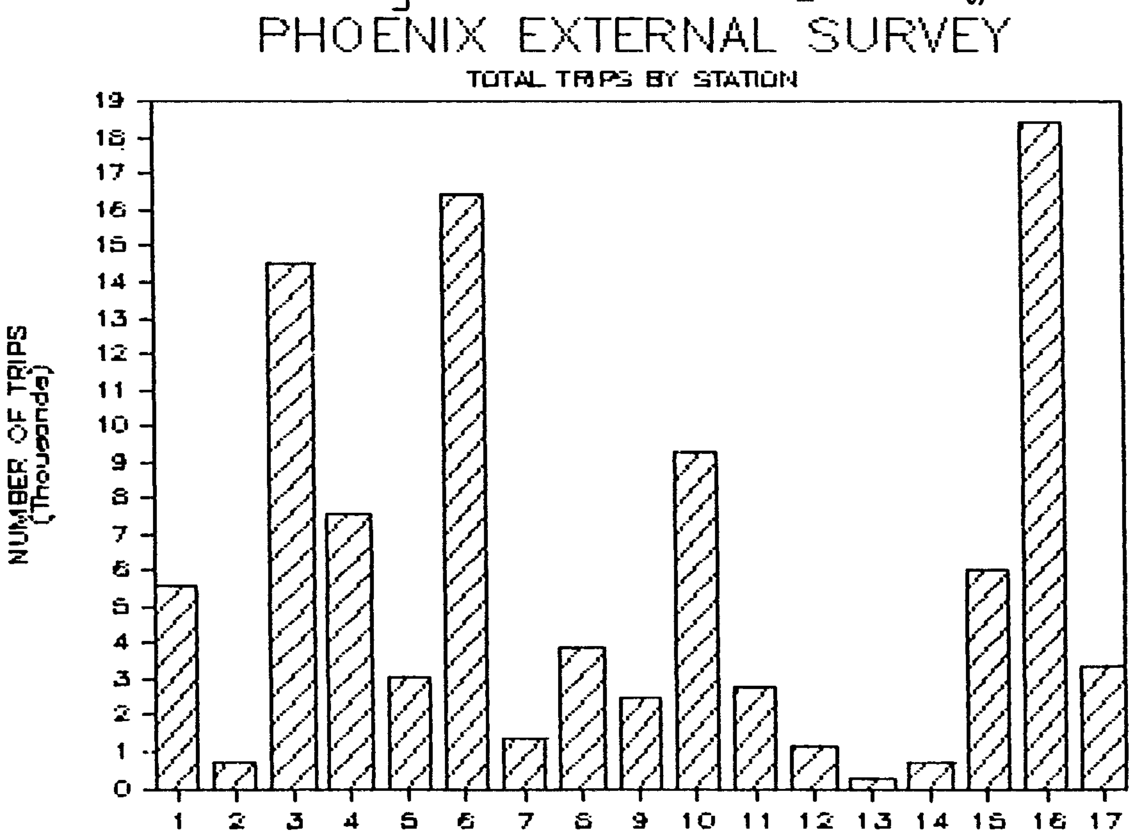

PHOENIX EXTERNAL SURVEY
AVG TRIP DISTANCE BY VEH TYPE
DISTANCE (MILES/10)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
AUTO
PUPV
RECV
MCYC
6TRK
6+TRK

EXHIBIT 10



PHOENIX EXTERNAL SURVEY
AVG TRIP LENGTH BY STATION
DISTANCE IN MILES
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
1 SR 85 (WEST)
2 BROADWAY
3 I-10 (WEST)
4 GRAND AVE.
5 LAKE PLEASANT
6 I-17 (NORTH)
7 CAVE CREEK
8 SR 87 (EAST)
9 SR 88 (EAST)
10 US 60 (EAST)
11 OCOTILLO RD.
12 ELLSWORTH RD.
13 POWER RD.
14 GILBERT RD.
15 SR 87 (SOUTH)
16 I-10 (SOUTH)
17 MARICOPA RD.



PHOENIX EXTERNAL SURVEY
TOTAL TRIPS BY STATION
NUMBER OF TRIPS
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

illustrated in Exhibits 11 and 12. Figure 11 shows the pattern of external - external trips; Exhibit 12, the pattern of external - internal trips to major subareas of the Phoenix region.

ALTERNATIVE MODEL STRUCTURES

The modeling of external trips involves two distinct steps -- the first related to trip generation and the second related to trip distribution. The trip-generation step almost certainly will involve some form of growth factoring. The growth factors may be global or specific to each station; they may be based on trends in traffic volumes or based on activity measures such as population or internal trip ends. The choice of growth-factor methodology is independent of the choice of trip-distribution methodology. Growth factors, either global or station-specific, will determine the magnitude of future external travel. These factors will be applied to observed external station volumes to yield future control totals to which the trip distribution will be balanced -- through either a fratar-type factoring procedure or a gravity model distribution procedure. Thus, the key decision relates to the most appropriate method of growth factoring.

An alternative and less typical approach is to combine both the trip generation and trip distribution steps into a single relationship. This approach would directly estimate trips at the interchange level in a single step -- often referred to as the direct demand model. This could be a particularly appropriate approach for the external trip model.

Based on the analysis of survey results, it seems unlikely that a *simple* synthetic model will be able to accurately reproduce the diverse external trip patterns observed. On the one hand, this fact could be overlooked on the basis that external trips represent only a small proportion of total

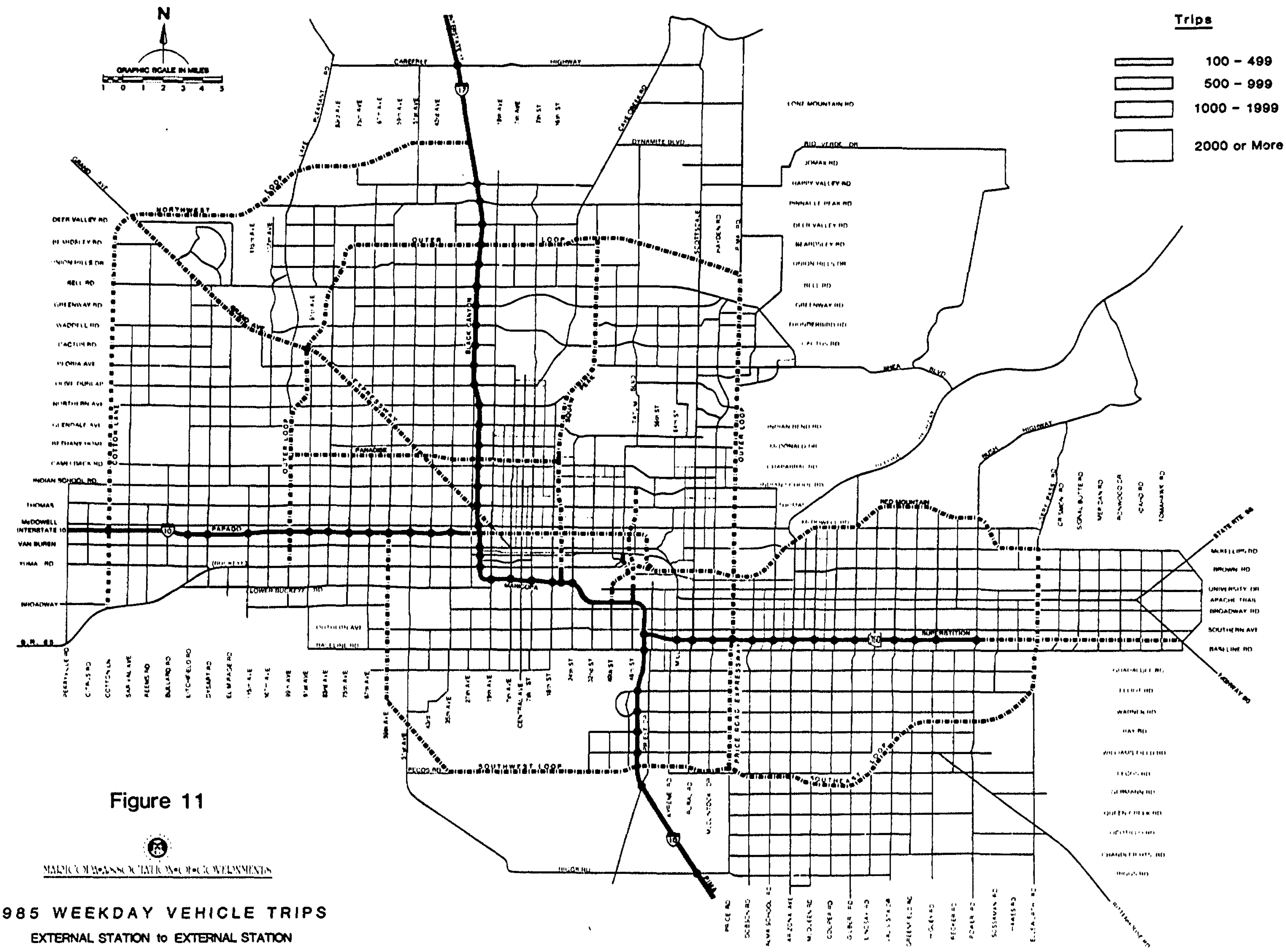


Figure 11

MARICOPA ASSOCIATION OF GOVERNMENTS

1985 WEEKDAY VEHICLE TRIPS

EXTERNAL STATION to EXTERNAL STATION

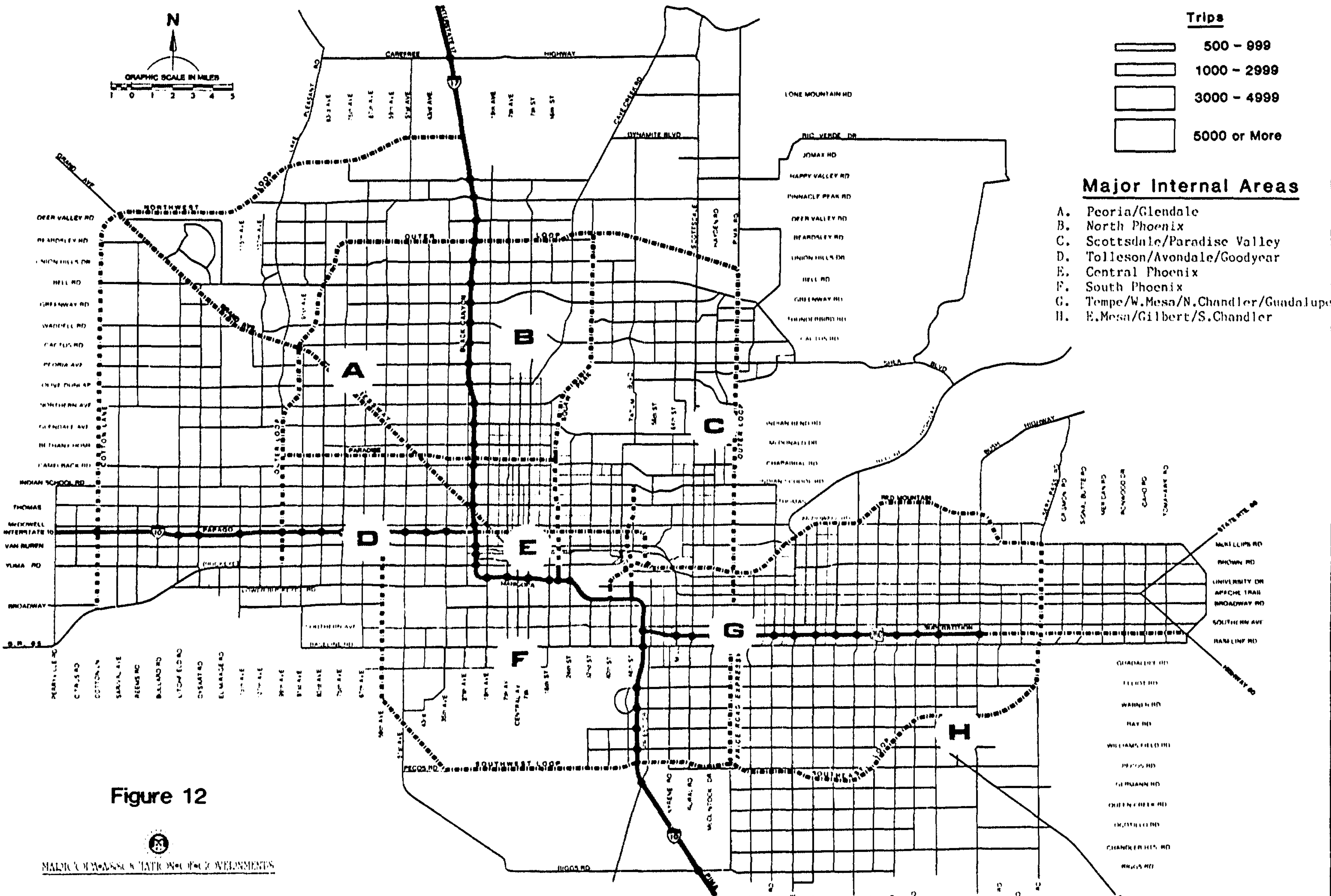


Figure 12

MARICOPA ASSOCIATION OF GOVERNMENTS

1985 WEEKDAY VEHICLE TRIPS

EXTERNAL STATION to MAJOR INTERNAL AREAS travel. On the other hand, is it best to develop a synthetic model? A synthetic model would be more complicated to derive and to apply and could produce less accurate results compared to growth factoring the actual survey results. The growth-factoring approach retains the unique patterns observed at each station and does not involve the time, cost and uncertainty associated with a synthetic model. However, the growth-factoring approach will not reflect major reorientations of travel demand due to growth in new development areas or due to major new highway facilities. A synthetic model potentially could reflect such influences.

The simplest approach, and not an unreasonable one, would be to build a single trip table containing all external survey trips. For a given forecast year, two factors could be developed for application to this table -- one based on total internal trip growth to be applied to interchanges with an internal end; the other to be applied to X-X trips based on historic travel growth, population growth in the Southwest, and/or other general activity measures.

An extension of this approach would be to allow factors to vary by station or station group. This approach would necessitate separation of X-X and I-X/X-I trips and use of a matrix-balancing procedure rather than the simple factoring of a single matrix. This approach, which is still quite simple to apply, would provide much greater flexibility and would produce superior results with modest additional effort. There are also a variety of hybrid approaches. For example, station-specific growth factors might be developed for some or all stations for I-X/X-I trips with a single global factor applied to all X-X trips.

Based on discussions of alternative approaches at the Technical Advisory Committee meeting held on February 12, 1986, it was decided that a synthetic model would be the most desirable approach. An approach similar to that applied to Arizona State University (ASU) trips was agreed upon as a basis for the external model. This approach will be applied to trips between external stations and internal zones. Trips between external stations will be handled by growth factoring. Truck trips will be handled separately from other vehicles.

6.

MODEL DEVELOPMENT

MODEL FORMULATION

Although an approach similar to that used for ASU trips will be employed for external-internal trips, the approach is complicated by the fact that there are multiple external stations. This complication could be dealt with by developing a separate relationship for each external station. However, a more desirable approach is to develop a generalized relationship that can adequately reflect the differing characteristics across all external stations. This would be particularly desirable from a transferability standpoint.

A generalized relationship may be formulated as follows:

$$T_{ij} = P_i * A_j * D_{ij}$$

where: T_{ij} = trips between external station i and internal zone j

P_i = the "productions" for station i

A_j = the "attractions" for zone j

D_{ij} = a function of the separation between station i and zone j

The terms "productions" and "attractions" are used in a generalized manner.

Given the data available for model development, productions can be a function of the observed trip ends at each station and attractions can be a function of several internal zonal variables such as households and employment by type.

Zonal separation can be a function of time or distance derived from coded highway networks. Time is preferred to distance as it is a better indicator of available travel facilities. Off-peak highway time is proposed since external trips are not concentrated in peak periods.

CALIBRATION DATA

Since the desired external model is to be applied on a station-to-zone interchange basis, it is necessary to create a calibration dataset on an interchange basis. The dataset created for this model is described below.

Three types of data are included in the dataset:

1. Total trip productions for each station by vehicle type;
2. Household and employment data by internal zone;
3. Station-to-zone off-peak highway time.

In order to prepare the external survey trip data for model development, trip tables were built for three vehicle types:

1. All non-truck vehicles;
2. Medium trucks;
3. Heavy trucks.

These tables were built from the survey data file in an origin-destination directional sense. For model development purposes, it was necessary to convert these tables to a production-attraction directional sense. This was accomplished by transposing each trip matrix then adding each table to its transpose, retaining only those interchanges representing external station-to-internal zone movements -- that is, the rows of the matrices corresponding to external stations (rows 1194 to 1210) and columns corresponding to internal zones (columns 1 to 1193). The row totals for rows 1194 to 1210 represent the total external station productions.

Zonal data for model development was obtained from MAG. This data included the following variables for the year 1985:

1. Total households;
2. Industrial employment;
3. Retail employment; and
4. Other employment.

Total households were taken from the standard UTPS TAZ Demand Forecasting Dataset. Employment data was based on a recent employment survey. This data is presented in Appendix C.

The file for model development was created using a special application of the UTPS program UMODEL. The resulting file includes a record for each station-to-zone interchange containing the following variables:

Type	Variable
I	OBSERVED OTHER VEHICLE TRIPS
I	OBSERVED MEDIUM TRUCK TRIPS
I	OBSERVED HEAVY TRUCK TRIPS
I	OFF-PEAK HIGHWAY TIME
P	OBSERVED OTHER VEHICLE PRODUCTIONS
P	OBSERVED MEDIUM TRUCK PRODUCTIONS
P	OBSERVED HEAVY TRUCK PRODUCTIONS
A	TOTAL HOUSEHOLDS
A	INDUSTRIAL EMPLOYMENT
A	RETAIL EMPLOYMENT
A	OTHER EMPLOYMENT

I = Interchange variable

P = Station production variable

A = Internal zone attraction variable

UMODEL setups for creation of the calibration file are presented in Appendix E. The calibration file created is designed for input to the UTPS calibration program UFIT, which was used to derive the model relationships as described below.

CALIBRATION PROCESS

The basic calibration procedure used to derive estimating relationships for external trips was multiple linear regression as implemented in the UTPS program UFIT. At the outset it was assumed that the relationships involved would be other than simple linear relationships. Thus various transformation strategies were investigated to deal with complex, non-linear relationships as well as tests involving simple linear forms. As indicated above, the general model formulation assumes three components:

1. A production component based on the observed trips at each station;

2. An attraction component assumed to be a composite relationship involving total households and employment by type at each internal zone; and

3. A travel time component.

These components in various forms comprise the independent variables. The observed trips from external stations to internal zones comprise the dependent variables. For example, the simple linear form was as follows:

$$T_{ij} = a * P_i + b * HH_j + c * IE_j + d * RE_j + e * OE_j + f * TIME_{ij}$$

where:

T_{ij} = observed trips from i to j for a vehicle type
HH_j = households at j;
IE_j = industrial employment at j;
RE_j = retail employment at j;
OE_j = other employment at j; and
$TIME_{ij}$ = off-peak time from i to j.

As hypothesized, this simple form produced very poor results in the UFIT runs. In order to utilize linear regression for complex, non-linear relationships, it is necessary to assume a basic formulation, then transform this into linear components.

In general form, the hypothesized relationship is as follows:

$$f(T_{ij}) = f(P_i) * f(HH_j, IE_j, RE_j, OE_j) * f(TIME_{ij})$$

where the variables within each function are defined as above.

This formulation is very similar to the numerator of the gravity model frequently used for modeling trip distribution. In this case, the model combines both generation and distribution. The complexity of the formulation is due primarily to the attraction and time components. Initially, the attraction component was assumed to be a weighted combination of the available attraction-type variables, which was termed AJ. The time component was assumed to follow a gamma-type distribution, which is a left-skewed, bell-shaped distribution often used for gravity model deterrence functions. This distribution has the following form:

f(TIME) = (TIME**a) * EXP(b*TIME)

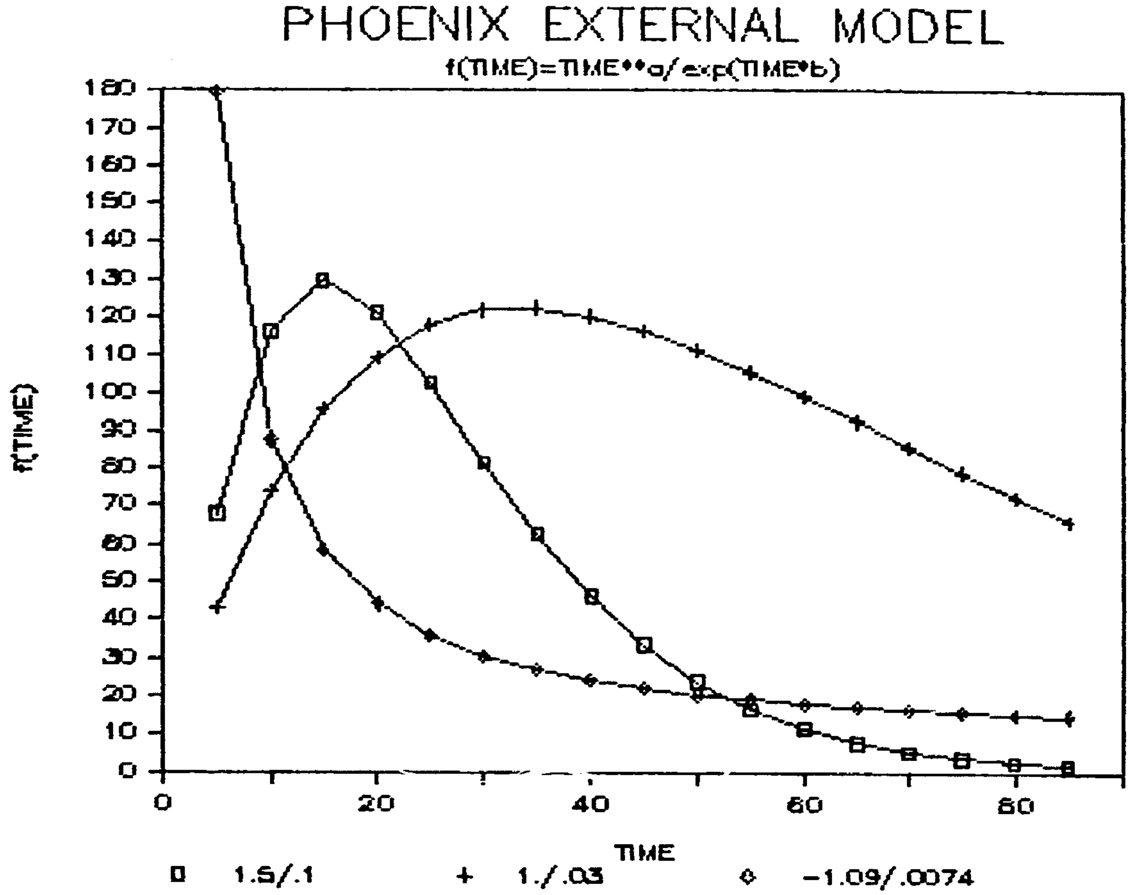
The shape of this distribution for various values of a and b is illustrated in Exhibit 13. Given these initial assumptions, the model can be expressed as:

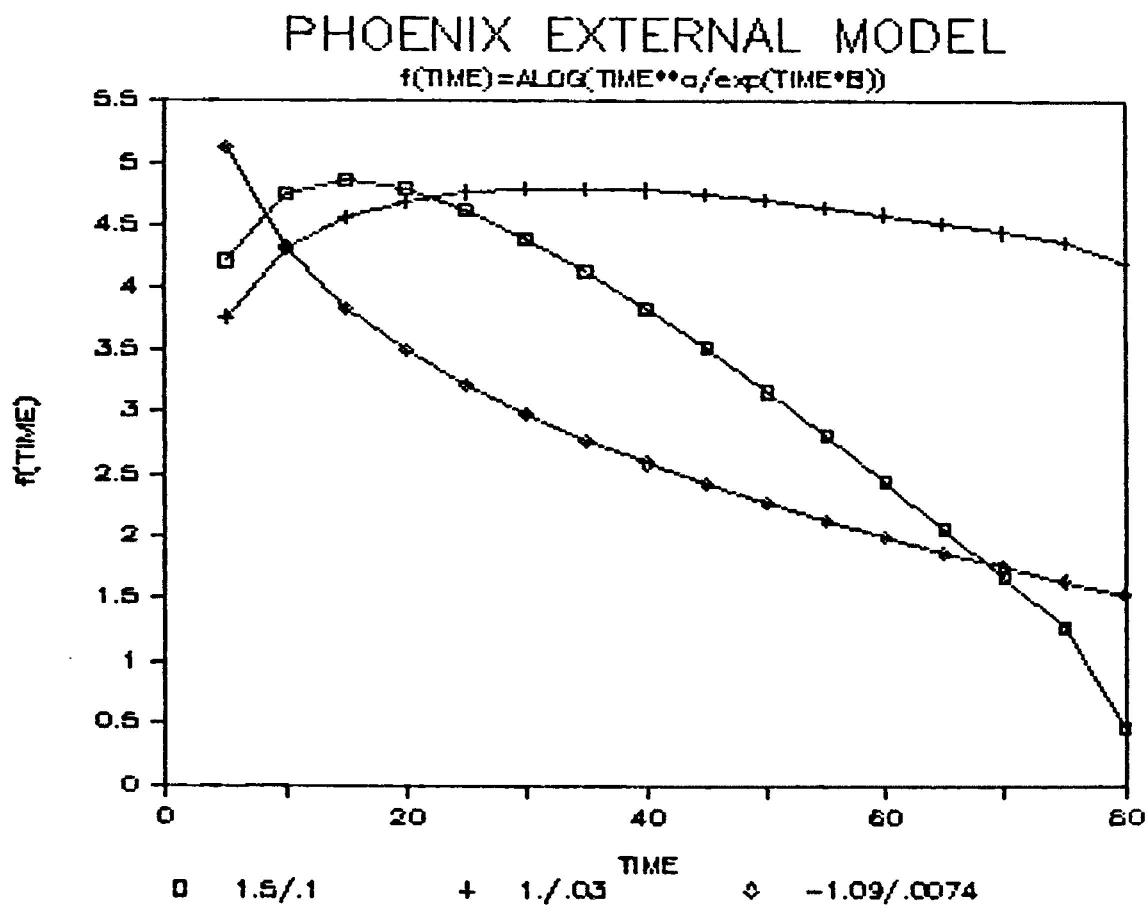
TIJ = PI * AJ * (TIME**a) * EXP(b*TIME)

This is clearly a non-linear relationship but can be transformed into additive, linear components by taking the LOG of both sides of the relationship yielding:

LOG (TIJ) = LOG (PI) + LOG (AJ) + a * LOG(TIME) + b * TIME

EXHIBIT 13


PHOENIX EXTERNAL MODEL
f(TIME)=TIME**a/exp(TIME*b)
f(TIME)
TIME
1.5/.1
1./.03
-1.09/.0074


PHOENIX EXTERNAL MODEL
f(TIME)=ALOG(TIME**a/exp(TIME*B))
f(TIME)
TIME
1.5/.1
1./.03
-1.09/.0074

Variations on this general form were evaluated using UFIT. The most promising results of these runs are summarized in Exhibit 14. A sample UFIT run is presented in Appendix F.

PRODUCTION MODEL

In order to apply the external trip model and evaluate its performance, the model was implemented within the UTPS program UMODEL. The user-coded subroutine for the model and the UMODEL application setup are presented in Appendix G. The model was applied using 1985 data and the results compared to observed survey data. Exhibit 15 presents the observed and estimated trip productions by vehicle type for each station. The model has been calibrated to accurately reproduce the productions at each station as indicated by Exhibit 15.

Exhibits 16-18 present observed versus estimated trip length frequency distributions. As indicated in these exhibits, the model also accurately reproduces the observed trip length distributions.

Exhibit 19 presents observed versus estimated trip attractions by vehicle type summarized by district (the zone-district equivalencies are included in Appendix D). While the comparisons in Exhibit 19 are not as satisfying as those in Exhibits 15-18, the model is doing as well as can be expected given the nature of the data involved. The trip matrices being estimated are very sparse, particularly for truck trips and especially for medium truck trips. Relatively few of the potential zone-to-zone interchanges have observed trips and the observed total trips from most of the stations is small in comparison to the number of potential destination zones. Given this situation, and recognizing that the survey data is also an estimate based on a sample survey, the model cannot be expected to reproduce survey

EXHIBIT 14

PHOENIX EXTERNAL MODEL - SUMMARY OF UFIT RUNS

	OTHER VEH. TRIPS (OTHVEH)			MED TRUCK TRIPS (MEDTRK)			HVY TRUCK TRIPS (HVYTRK)		
COEFF.	VALUE	STD.ERR.	t-RATIO	VALUE	STD.ERR.	t-RATIO	VALUE	STD.ERR.	t-RATIO
A1	1.67600	0.08990	18.60	0.23960	0.04010	5.97	0.48080	0.06390	7.52
A2	0.31290	0.00580	54.20	0.00370	0.00110	3.46	0.02170	0.00123	17.70
A3	NA	NA	NA	0.00001	0.000003	4.11	0.000080	0.000004	1.90
A4	1.01520	0.01960	51.70	0.00061	0.00105	0.58	0.00245	0.00169	1.45
A5	NA	NA	NA	0.00400	0.00080	5.01	0.01630	0.00130	12.70
A6	0.00024	0.00001	21.80	0.00083	0.00032	2.56	0.00210	0.00050	4.02
A7	0.02645	0.00416	6.37	-0.07520	0.01450	-5.19	-0.17590	0.02330	-7.55
A8	0.01870	0.00320	5.91	0.00035	0.00083	0.42	-0.00046	0.00133	-0.34
A9	0.02230	0.00330	6.81	NA	NA	NA	NA	NA	NA

REGRESSION EQUATIONS:

LOG(OTHVEH) = A1 + A2*LOG(OTHVEHPR) + A4*LOG(exp(0.0074*TIME)/TIME**1.09) + A6*TOTHH
+ A7*LOG(RETEMP) + A8*LOG(INDEMP) + A9*LOG(OTHEMP)

LOG(MEDTRK) = A1 + A2*LOG(MEDTRKPR) + A3*TOTHH + A4*LOG(RETEMP) + A5*LOG(INDEMP)
+ A8*LOG(OTHEMP) + A6*TIME + A7*LOG(TIME)

LOG(HVYTRK) = A1 + A2*LOG(HVYTRKPR) + A3*TOTHH + A4*LOG(RETEMP) + A5*LOG(INDEMP)
+ A8*LOG(OTHEMP) + A6*TIME + A7*LOG(TIME)

NOTE: RETEMP WAS DROPPED FROM MEDTRK AND OTHEMP FROM BOTH MEDTRK AND HVYTRK
DUE TO LOW SIGNIFICANCE

EXHIBIT 15

PHOENIX EXTERNAL MODEL - OBSERVED VS ESTIMATED PRODUCTIONS

STATION	OTHER VEHICLES OBS	OTHER VEHICLES EST	MEDIUM TRUCKS OBS	MEDIUM TRUCKS EST	HEAVY TRUCKS OBS	HEAVY TRUCKS EST
1194	4555	4591	178	224	348	476
1195	513	697	36	49	18	26
1196	9193	9201	255	292	2339	2349
1197	6459	6498	204	225	277	321
1198	2467	2559	41	42	91	101
1199	13016	13001	315	662	1199	1049
1200	1239	1141	28	8	5	34
1201	3367	3355	73	125	170	446
1202	2202	2149	45	13	96	125
1203	8010	8006	230	124	480	454
1204	2442	2465	106	144	111	111
1205	1105	1030	26	20	12	18
1206	276	411	5	0	12	23
1207	671	1028	30	41	17	39
1208	5082	5072	219	425	462	501
1209	12683	12673	484	607	2563	2582
1210	2989	2923	78	358	211	195
TOTAL	76269	76800	2353	3359	8411	8850

EXHIBIT 16

```
 EST AND OBS OTHER VEH TRIPS VS OFF-PEAK TIME
OBSERVED (-) AND ESTIMATED (+)   TRIP LENGTH FREQUENCY DISTRIBUTIONS
OBSERVED =  UMCON   (TABLE 2001)   ESTIMATED =  UMODEL  (TABLE 3001)
               SKIM TREE =  OFPK TIM(TABLE 1001)
                    (COUNTS SCALED BY  10)
   0    2    4    6    8   10   12   14   16   18   20     COUNTS     RATIO
   +----+----+----+----+----+----+----+----+----+----+    (+)  (-)  (+)/(-)
  0*                                                         0    0     0.0
  5*--                                                       2   51     0.0
 10**--                                                     42   90     0.5
 15********-------------                                   223  599     0.4
 20**************--------                                  404  639     0.6
 25***********************-                                688  716     1.0
 30******************************++                        963  875     1.1
 35**********************************++++++++             1258  999     1.3
 40******************************+++++++++                1172  899     1.3
 45***************************++++                         930  807     1.2
 50********************+++                                 688  585     1.2
 55***************++                                       498  425     1.2
 60************+                                           371  325     1.1
 65*********-                                              236  267     0.9
 70*****                                                   120  132     0.9
 75***-                                                     52   86     0.6
 80**-                                                      23   55     0.4
 85*-                                                        4   43     0.1
 90*-                                                        1   22     0.1
 95*                                                         0    6     0.0
100*                                                         0    7     0.0
105* (ALL REMAINING COUNTS ARE ZERO)                         0    0     0.0
         MEAN       VARIANCE      STD DEV   TOTAL COUNT               AREA
         ----       --------      -------   -----------               ----
  (+)  37.201   (+)  175.127  (+) 13.234  (+)     76762   COINCIDENT  87.837
  (-)  35.629   (-)  260.902  (-) 16.152  (-)     76290        TOTAL 112.163
```

EXHIBIT 17

```
  EST AND OBS MED TRK TRPS VS OFF-PEAK TIME
 OBSERVED (-) AND ESTIMATED (+)   TRIP LENGTH FREQUENCY DISTRIBUTIONS
 OBSERVED =  UMCON   (TABLE 2002)   ESTIMATED =  UMODEL  (TABLE 3002)
                SKIM TREE =  OFPK TIM(TABLE 1001)
  0    4    8   12   16   20   24   28   32   36   40    COUNTS    RATIO
  +----+----+----+----+----+----+----+----+----+----+   (+)  (-)  (+)/(-)
 0*                                                       0    0     0.0
 5*                                                       0    2     0.0
10*-                                                      0   19     0.0
15*-----                                                  0   87     0.0
20*-----                                                  4   93     0.0
25******-----                                           130  195     0.7
30**************++++++++++++++++                        787  241     3.3
35************************++++++++++++++++++++++++     1270  441     2.9
40****************+++++++++++++++++                     862  286     3.0
45*********-------                                      202  273     0.7
50*****-----                                            103  167     0.6
55*---                                                    1   49     0.0
60*----------                                             0  185     0.0
65*-----------                                            0  208     0.0
70*----                                                   0   84     0.0
75*-                                                      0   13     0.0
80*                                                       0    0     0.0
85*                                                       0    0     0.0
90*                                                       0    0     0.0
95*                                                       0    0     0.0
100*-                                                     0   10     0.0
105* (ALL REMAINING COUNTS ARE ZERO)                      0    0     0.0
        MEAN       VARIANCE     STD DEV   TOTAL COUNT                AREA
        ----       --------     -------   -----------                ----
  (+)  33.274  (+)   28.844  (+)  5.371  (+)      3359  COINCIDENT  54.238
  (-)  39.213  (-)  233.445  (-) 15.279  (-)      2353       TOTAL 145.762
```

EXHIBIT 18

```
  EST AND OBS HVY TRK TRPS VS OFF-PEAK TIME
 OBSERVED (-) AND ESTIMATED (+)   TRIP LENGTH FREQUENCY DISTRIBUTIONS
 OBSERVED =  UMCON   (TABLE 2003)   ESTIMATED =  UMODEL  (TABLE 3003)
                SKIM TREE =  OFPK TIM(TABLE 1001)
 0    4    8   12   16   20   24   28   32   36   40     COUNTS     RATIO
 +----+----+----+----+----+----+----+----+----+----+    (+)  (-)  (+)/(-)
 0*                                                       0    0      0.0
 5*                                                       0   31      0.0
10*                                                      14   23      0.6
15****---                                               210  394      0.5
20********--                                            481  604      0.8
25*********++++++                                      1058  602      1.8
30*********************+++                             1574 1252      1.3
35************************++++                         1831 1495      1.2
40**************+++++++++                              1470  760      1.9
45****************-----------                          1048 1737      0.6
50********+++                                           652  384      1.7
55******--                                              328  467      0.7
60***-                                                  174  203      0.9
65*-----                                                 11  350      0.0
70*                                                       0   21      0.0
75*                                                       0   24      0.0
80*-                                                      0   64      0.0
85* (ALL REMAINING COUNTS ARE ZERO)                       0    0      0.0
       MEAN       VARIANCE      STD DEV   TOTAL COUNT                AREA
       ----       --------      -------   -----------                ----
 (+)  33.476  (+)   98.949  (+)  9.947  (+)      8851  COINCIDENT  79.020
 (-)  35.555  (-)  172.426  (-) 13.131  (-)      8411       TOTAL 120.980
```

EXHIBIT 19

PHOENIX EXTERNAL MODEL - OBSERVED VS ESTIMATED ATTRACTIONS

DISTRICT	OTHER VEHICLES OBS	OTHER VEHICLES EST	MEDIUM TRUCKS OBS	MEDIUM TRUCKS EST	HEAVY TRUCKS OBS	HEAVY TRUCKS EST
1	589	677	14	19	0	64
2	1217	1362	56	78	35	220
3	2618	3011	28	112	121	334
4	516	716	0	23	10	86
5	1085	1659	34	78	11	246
6	1905	1853	34	74	67	178
7	654	1163	14	47	20	149
8	2232	1593	34	52	47	140
9	553	830	20	21	19	74
10	1210	1323	51	32	0	118
11	623	429	11	16	63	48
12	901	1272	7	21	132	192
13	3062	2601	71	145	194	323
14	2841	1580	49	58	493	120
15	1322	2204	124	73	112	213
16	375	516	0	17	13	51
17	421	403	10	14	15	43
18	540	588	0	10	83	37
19	990	856	14	26	76	122
20	1499	1285	15	69	197	127
21	2265	1512	32	78	344	127
22	3158	3124	50	180	132	339
23	1953	2128	48	113	82	196
24	1566	1836	26	70	46	173
25	1627	1138	23	23	86	151
26	2025	1576	16	33	511	238
27	196	329	2	14	13	34
28	694	1304	59	87	584	230
29	2507	2004	322	145	950	237
30	745	1094	53	85	464	156
31	2378	2703	164	198	433	364
32	1797	1905	122	87	277	202
33	2588	1313	39	67	432	186
34	2205	1924	53	69	214	208
35	3302	3166	117	174	264	350
36	1414	1979	104	133	4	236
37	2240	4667	44	249	194	561
38	2035	3816	118	215	715	536
39	2255	1687	27	29	113	160
40	2050	1460	118	42	133	185
41	3611	798	34	11	160	56
42	449	204	0	2	37	23
43	867	1451	12	16	91	141
44	197	491	6	0	37	52
45	2515	1449	72	30	202	148
46	1218	2662	38	131	70	364
47	761	1588	25	23	59	109
48	2498	1502	43	67	56	204
TOTAL	76269	76731	2353	3356	8411	8851

attractions with a high degree of accuracy. Where the number of trips involved is relatively large as for the other vehicle trips, there is general agreement between the observed and estimated attractions as indicated in Exhibit 19 and as further illustrated in Exhibit 20. If a few outliers are eliminated from Exhibit 20, the general result looks much improved.

The "outgoing" districts are as follows:

37 = Mesa vicinity

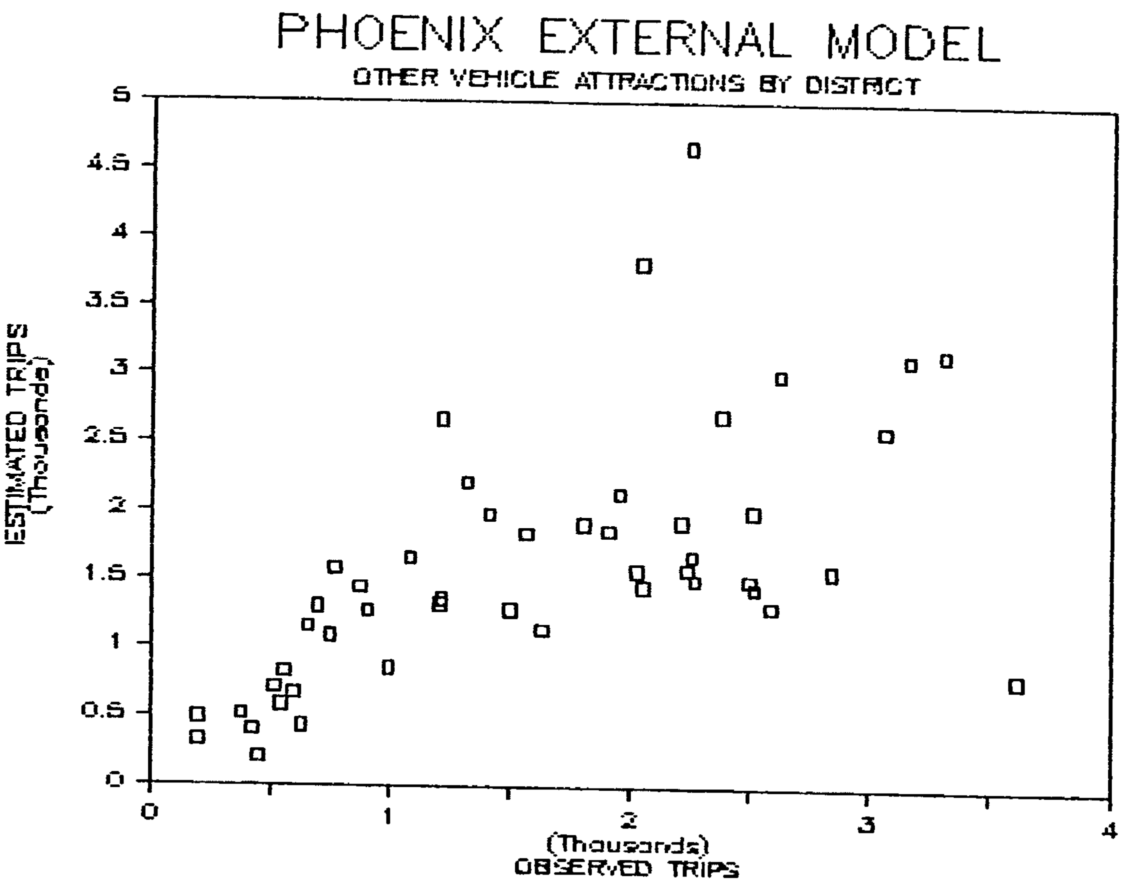
38 = South Central Area from Apache down to Reccor including South Moutain Park

41 = Eastern extremity of regions - Apache Junction

46 = Gilbert area -- far SE

Districts 37, 38 and 46 are comprised of a large number of zones; they do not represent the large generators as such. District 41 has a problem in the observed data as can be seen by reference to Appendix D. The district summary of data in Appendix D indicates there are some substantial discrepancies between the alternative sources of data. We have used the employment data from Source 2 (Recent Employment Survey). Data weaknesses in these outlying zones may be affecting other districts as well. Thus, the statistically "outlying zones" are in fact geographically outlying areas. The model appears to be overestimating trips in these outlying areas. However, this is where the internal models typically produce the least good results; hence, the potential error in the external model is not likely destroying what is otherwise a good estimate. Appendix H presents a statistical comparison of observed versus estimated values, with and without the four outlying districts indentified above.

EXHIBIT 20


PHOENIX EXTERNAL MODEL
OTHER VEHICLE ATTRACTIONS BY DISTRICT
ESTIMATED TRIPS
(Thousands)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
(Thousands)
OBSERVED TRIPS

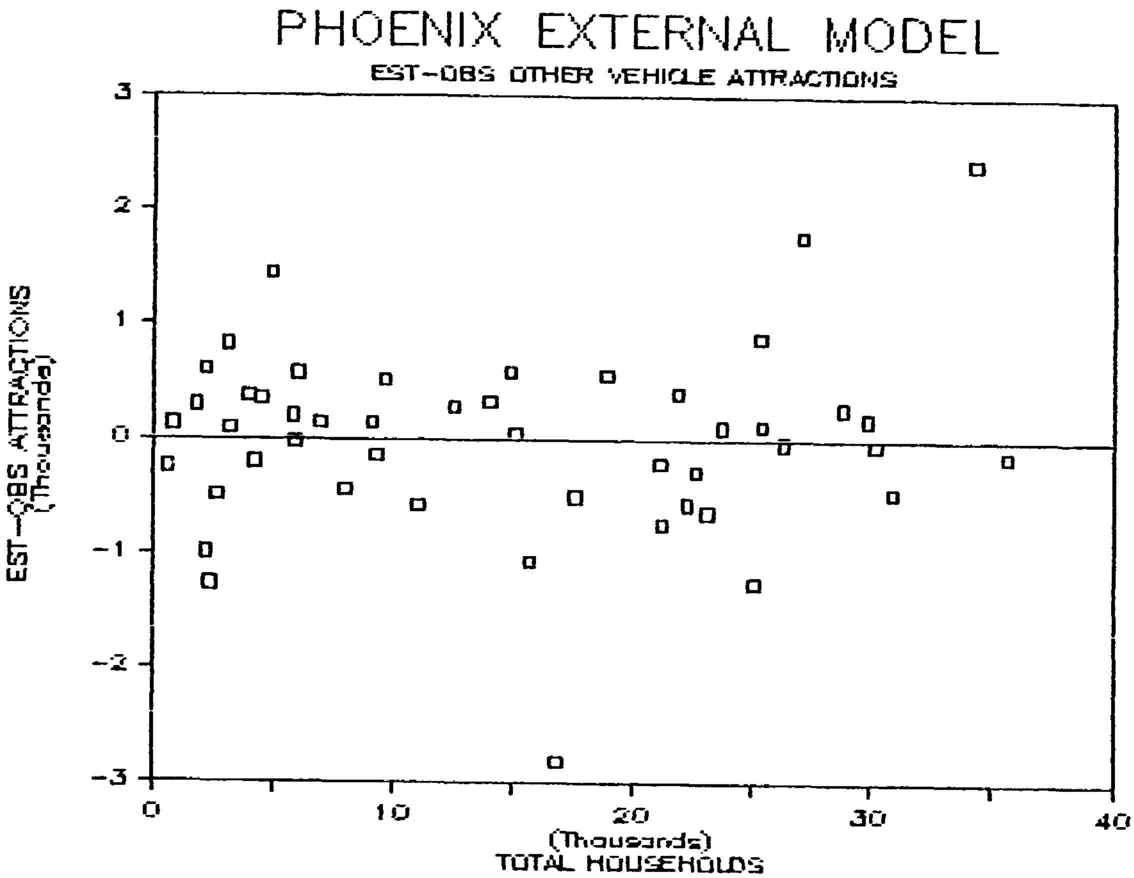
In order to ensure that the model is utilizing the available attraction variables to best advantage, scatter plots of the EST-OBS error for other vehicle trips were prepared as shown in Exhibits 21-24. These exhibits plot EST-OBS other vehicle attractions by district versus total households (Exhibit 21), versus industrial employment (Exhibit 22), versus retail employment (Exhibit 23), and versus other employment (Exhibit 24). If any one of these plots indicated an unbalanced or biased distribution of the error term against an attraction variable, it would mean that attraction variable was poorly represented in the model. Exhibits 21-24 do not indicate the presence of any strong bias in the model estimates with respect to any one of the attraction variables. It is concluded, therefore, that the model is doing as well as can be expected and indeed is doing quite a good job of reproducing the general levels of travel demand produced by external stations both in number and in terms of vehicle miles of travel (VMT) as indicated by the trip length frequency distributions.

TRANSFERABILITY

Given the generalized structure of the external model development for Phoenix, the model could be readily adapted for use in another urban area. Recalibrations of the model would be essential, however. At a minimum, such recalibration would involve developing factors for each station to bring the total station productions into balance with counted volumes at each station. An O-D survey would not be necessary, just traffic counts by the three vehicle types used in the model. It would also be possible to combine medium trucks with other vehicle trips within the model for greater stability. In fact, this would be recommended.

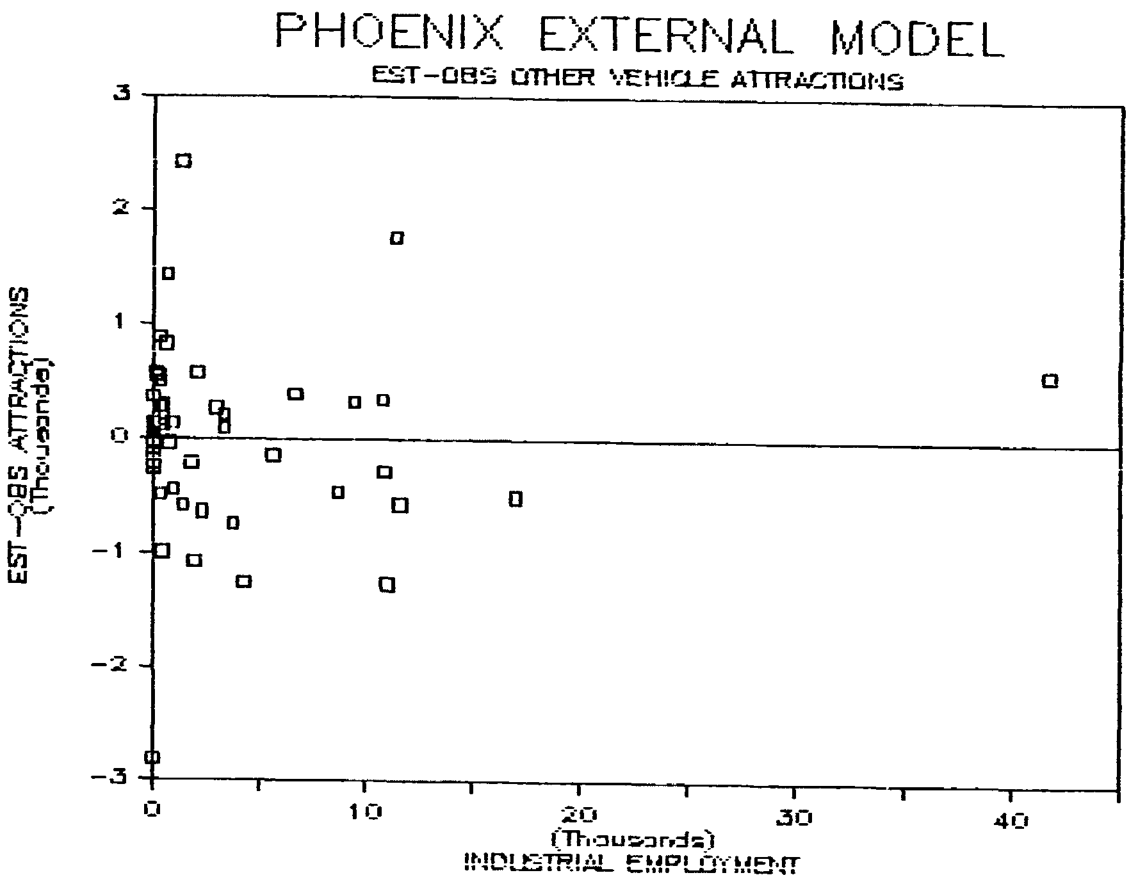
In addition to traffic counts at each station, attraction variables as embodied in the Phoenix model would have to be available for the area in

EXHIBIT 21



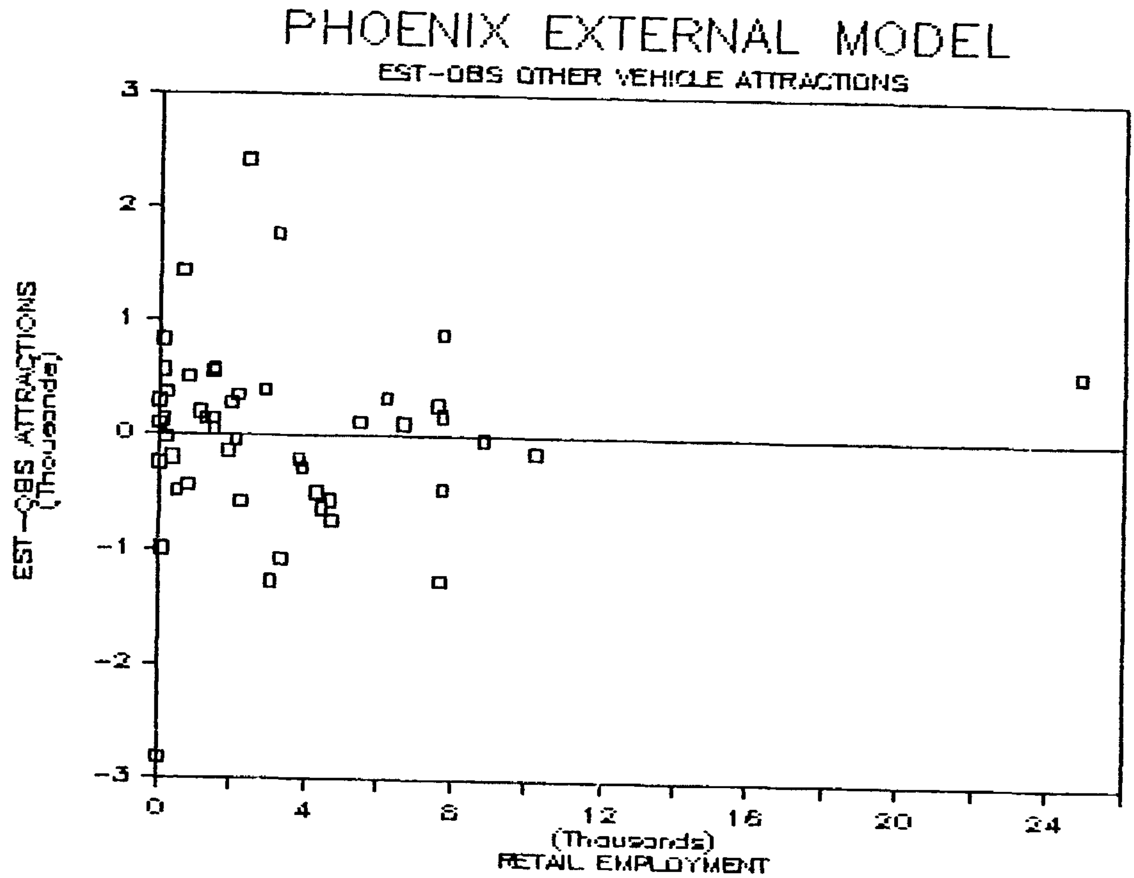
PHOENIX EXTERNAL MODEL
EST-OBS OTHER VEHICLE ATTRACTIONS
EST-OBS ATTRACTIONS (Thousands)
3
2
1
0
-1
-2
-3
0
10
20
30
40
(Thousands)
TOTAL HOUSEHOLDS

EXHIBIT 22



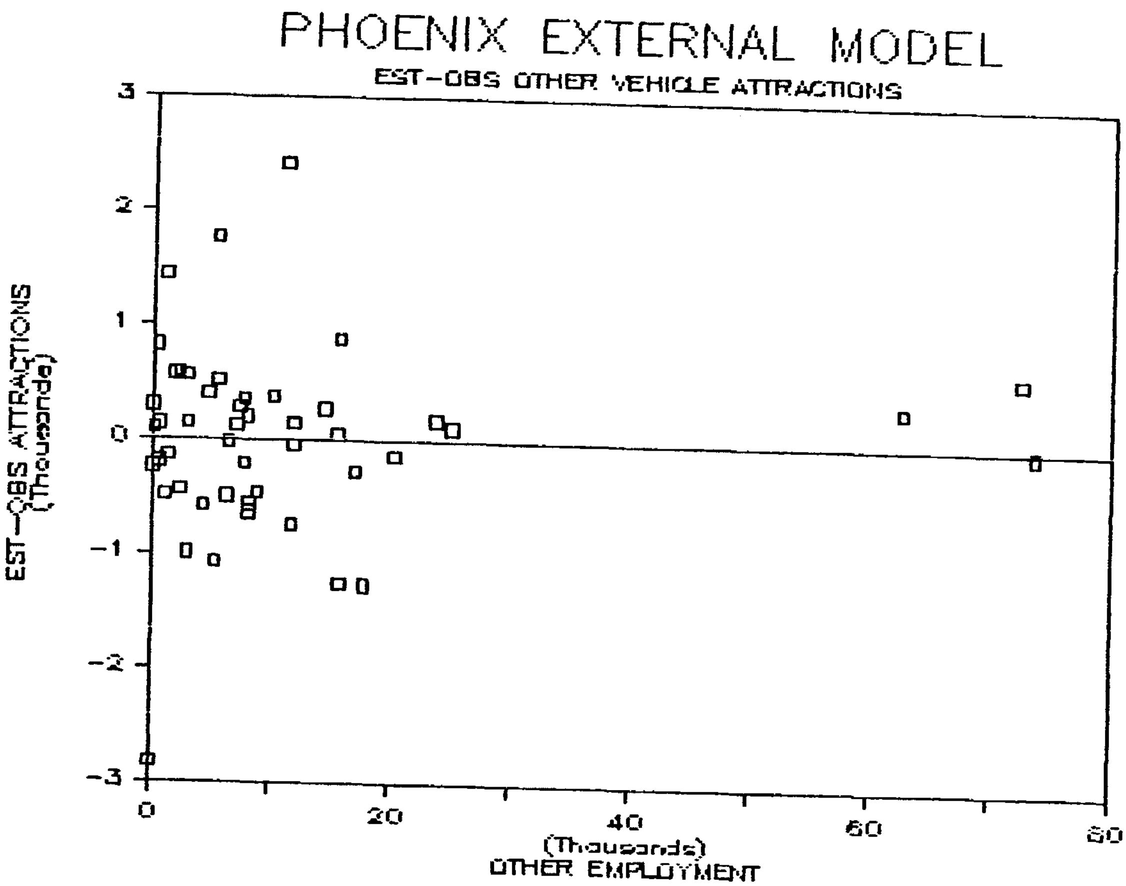
PHOENIX EXTERNAL MODEL
EST-OBS OTHER VEHICLE ATTRACTIONS
EST-OBS ATTRACTIONS (Thousands)
3
2
1
0
-1
-2
-3
0
10
20
30
40
(Thousands)
INDUSTRIAL EMPLOYMENT

EXHIBIT 23



PHOENIX EXTERNAL MODEL
EST-OBS OTHER VEHICLE ATTRACTIONS
EST-OBS ATTRACTIONS
(Thousands)
3
2
1
0
-1
-2
-3
0
4
8
12
16
20
24
(Thousands)
RETAIL EMPLOYMENT

EXHIBIT 24



PHOENIX EXTERNAL MODEL
EST-OBS OTHER VEHICLE ATTRACTIONS
EST—OBS ATTRACTIONS
(Thousands)
3
2
1
0
-1
-2
-3
0
20
40
60
80
(Thousands)
OTHER EMPLOYMENT

question. The breakdown of employment as used for Phoenix may present a problem in other urban areas. If so, it would be possible to use the Phoenix calibration dataset to restructure the model in a manner consistent with the data available in the target urban area.

A further refinement in the adaptation of the model to another area is suggested -- the adjustment of average trip lengths based on comparative urban area size and/or comparative internal area average trip lengths. If a rational basis is available for estimating average trip lengths for the target area, then the model constants can be adjusted to reproduce these estimates.